DR. D. M. BOSE SEVENTIETH BIRTHDAY COMMEMORATION VOLUME

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FOUNDED IN 1918 BY SIR J. C. BOSE

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FOREWORD

The decision to commemorate in a fitting manner the seventieth birthday of Dr. D. M. Bose was taken at a meeting held on May 28, 1954, under the chairmanship of Dr. S. K. Mitra, Ghosh Professor of Physics, Calcutta University. At this meeting, which was convened by his students, colleagues and admirers, the DR. D. M. BOSE SEVENTIETH BIRTHDAY CELEBRATION COMMITTEE was formed, with Dr. D. P. Rai Choudhury as Chairman and Professor H. P. De and Dr. S. D. Chatterjee as Secretaries.

To commemorate this happy occasion and as a part of the celebrations, it was decided to publish a special volume of the *Transactions of the Bose Research Institute* containing original and review articles. Accordingly invitations were sent out to prominent scientists at home and abroad. The subject-matter and size of the contributions were left to the discretion of the authors.

We take this opportunity to acknowledge with gratitude the warm response to our appeal and the kind co-operation we have received from the foreign scientists as well as our own.

Our special thanks are due to the Governing Body of the Bose Institute for its generosity in defraying the expenses without which it would not have been possible for us to bring out this volume. Our thanks are also due to the Baptist Mission Press, who have willingly extended their full co-operation in seeing it through the press with admirable expedition.

This volume contains twenty papers on various scientific subjects which are printed in the order they were received. We trust, by the richness of its contents, this volume will be worthy of acceptance by the distinguished teacher to whom it is dedicated. Once again we thank those who have devoted their precious time to enrich its pages.

We offer to Dr. D. M. Bose this volume as a modest token of our love, admiration and reverence.

CALCUTTA,
March 6, 1955

DR. D. M. BOSE SEVENTIETH BIRTHDAY
CELEBRATION COMMITTEE

CONTENTS

DR. D. M. BOSE

Born 26 November, 1885

DEBENDRA MOHAN BOSE—HIS LIFE AND ACTIVITIES

Truth, application, rectitude of conduct and width of vision—these are the paths which have led ancient Indian savants to the sunlit heights of fame. On the other hand, in his *Modern Science and Modern Man*, James B. Conant observes that 'the notion that a scientist is a cool, impartial, detached individual is, of course, absurd. The vehemence of conviction, the pride of authorship burn as fiercely among scientists as among any creative workers'. This apparent contradiction may be explained by the hypothesis that though 'science is ordered technique', it began as 'rationalized mythology'. Indeed, Prof. J. D. Bernal reminds us that 'it started as a hardly distinguishable aspect of the mystery of the craftsman and the lore of the priest'.

The most attractive feature in the life of Dr. D. M. Bose is the blend therein of the orient and the occident. He combines Eastern meditativeness with the Western belief in the scrutability of Nature, and unites the 'temper of the visionary with that of the man of the world'. His preoccupation with scientific research has never forced him to abandon that essential humanism which characterizes all creative thinkers. It is in this context that we have to evaluate the work of Bose as a scientist and as a man.

Seen through the mist of years, his early life appears to be a fascinating episode. Debendramohan Bose was born in Calcutta on November 26, 1885. His ancestral home was at Joyshidhi in the district of Mymensing, now in East Pakistan. His father, Mohinimohan Bose, was probably one of the first Indians to have visited the United States of America. He studied homeopathy there and, on his return to his native country, set up practice as a physician and also as a teacher of this particular branch of learning. His uncle Anandamohan Bose was the first Indian Wrangler in Mathematical Tripos of Cambridge. Though he was called to the bar, he spent his life in religious, educational and political work. He was one of the pioneers who brought about the renaissance of modern Bengal. His contribution to the service of his motherland was duly recognized when he was elevated to the presidentship of the Indian National Congress in the year 1898.

Debendramohan's mother was Sir J. C. Bose's younger sister. It is, therefore, not surprising that he should be the heir (in more senses than one) of his illustrious uncle. Acharya Jagadish Chandra was without a son and Debendramohan's father died early. Thus, he came under the tutelage of his maternal uncle in his childhood and was constantly helped and guided by his advice. His mother was a very remarkable lady. She devoted most of her later years, when her own sons were grown up, in looking after the education and welfare of children of relatives who lived in distant lands and orphans. Many relatives and friends were received in her house for nursing and medical treatment. She once nursed the ailing Pandit Sivanath Sastri back to health.

Debendramohan's early education started at the Brahmo Girls' School, then located at 13 Cornwallis Street, Calcutta. Afterwards he entered the City School and passed his Entrance Examination from there. Acharya Jagadish Chandra used to live with Debendramohan's father in the latter's family home at 64/1 Machuabazar Street. It was to this house again, that Acharya Prafulla Chandra Ray came on his return from Edinburgh to live with his friend. The house was situated on a level lower than the surrounding plots of land. This meant that whenever there was a heavy shower, there would be great fun. Rafts would be made, boats would be borrowed, and young Debendra-

mohan and his companions would practise the art of the complete angler with a fair amount of success. In 1901, the family shifted to their present home at 92/3 Upper Circular Road.

Those were the days of great hopes and aspirations. Many national projects were in the offing. Sir Prafulla Chandra who had then removed to 91 Upper Circular Road founded the Bengal Chemicals. He would come and play with young Bose and his associates. The children who ran errands for Sir P. C. would be rewarded with the 'Syrup of Rose' from his newly started concern. Pandit Sivanath Sastri and Sir Nilratan Sircar were also frequent visitors. Thither, and later to his uncle's house at 93 Upper Circular Road, also came Rabindranath Tagore, Loken Palit, Sarala Debi, Charu Chandra Datta, and Sister Nivedita of dedicated life. In this unique atmosphere of scientific, spiritual and literary culture young Debendramohan was brought up. There were other inspiring figures too. The Swedish scholar, M. Hammergren, had come all the way from his native land to gather materials about Raja Rammohan Roy and the Brahmo Samaj. He taught the children swimming and languages. It was he who interested young Bose in continental masters like Goethe, Schiller and Ibsen. Dr. Bose also remembers with much amusement his astounding technique of imbibing cod-liver oil (that horror of children) without the slightest facial contortion.

From the beginning, Debendramohan was interested in all those activities which any healthy boy of his age was expected to be interested in. For example, very few people know that he was a versatile sportsman. He was one of the founders of the Sporting Union Club—a club, which in this land of temporary enthusiasms, has had a miraculous life of more than half-a-century. Young Bose was the captain of the Hockey Team of the Sporting Union Club in 1905-6. While he was a student of the Presidency College he excelled his classmates in cycling, football and cricket. He won several cups in these activities and recalls with pleasure the fact that he was a member of the team which won the Elliott Shield for the Presidency College.

It was originally intended that Debendramohan would have to be an engineer. With that aim in view, he went to the Engineering College at Sibpur. Unfortunately, he went down with fever there and had to give up the idea of returning to that malaria-infested seat of learning again. Poona was thought to be a better choice for a degree in engineering. As, however, some knowledge of geology was essential for engineers, he got himself admitted into the B.Sc. classes of the Presidency College with geology as one of his subjects.

It was at this stage that fate intervened. Acharya Jagadish Chandra who started getting sensational results from his researches on the responses in the Living and Non-living, decided that his nephew would have to study pure science. Otherwise his epoch-making work, in the absence of properly trained scientists who understood its implications, would die a premature death. It was thus that Dr. D. M. Bose became a physicist. In 1906, he passed his M.A. examination in Physics from the University of Calcutta with the highest distinction. For a year he worked under his uncle as a research assistant. In 1907, he joined the Christ's College at Cambridge, where he had the privilege of working at the Cavendish Laboratory under the great Sir J. J. Thomson. In 1912 Dr. Bose passed his B.Sc. with honours in Physics from the Royal College of Science, affiliated to the University of London. Returning home, he worked as a lecturer in the City College, Calcutta, for one year, when he was called upon to occupy the newly founded chair of physics as Sir Rashbehary Ghosh Professor in the University College of Science, Calcutta. In 1914, he visited Germany for further study. Unfortunately, the First World War intervened and he was interned in Germany for some time. Later he was permitted to

continue his studies, but he could not proceed to his doctorate examination before the termination of the war. In Berlin Bose attended lectures by many of the leading German physicists of the day, Planck, Einstein and others, and did his thesis work in Regener's laboratory. At this time further developments of the quantum theory by Planck, Einstein and Sommerfeld were taking place. Lively debates on Einstein's Special Relativity Theory were going on while his Generalized Theory was being developed. One of Einstein's favourite expression was that 'the good (gute) God was always wiser than all theoretical physicists', a remark comparable to another of his oft-quoted recent one 'I cannot believe in a dice-throwing God'. Bose used to attend the colloquium of Rubens, which during the war became the meeting place of the leading German physicists, including Nernst, Warburg, Franck, Hertz, Pohl, Born and many others. He obtained his Ph.D. of the Berlin University in March, 1919, and returned to Calcutta *via* London in July, 1919. He continued to hold the Ghosh Chair of Physics till 1935 when he succeeded Sir C. V. Raman as Palit Professor. On the passing away of Acharya Jagadish Chandra Bose, he was appointed Director of the Bose Institute in April, 1938—a post which he still adorns.

In 1919 after his return from Europe, Dr. D. M. Bose married Srimati Nalini Sircar, the eldest daughter of Sir Nil Ratan Sircar. She has been a worthy consort of her scientist husband through the manifold phases of his life—its brilliant sunshine and its weeping gloom. They have had three sons in Debabrata Bose, Sunanda Bose and late Supriya Bose. Endowed with rare intelligence and refreshing candour, they have maintained the tradition of this highly talented family.

Dr. D. M. Bose was President of the Physics Section of the Indian Science Congress in 1927. The same year in August he attended the International Congress of Physics at Como, Italy, held in connection with the Volta Centenary. He also revisited London in 1933, as an Indian delegate to an international congress.

His investigations fall under three principal groups:

(i) The study of nuclear collisions and disintegration by means of Wilson cloud chamber and photographic emulsions. Determination of the mass of mu-mesons by the photographic emulsion method.

(ii) The study of properties of simple and complex compounds containing paramagnetic and rare-earth ions. Interpretation of their magnetic moments in terms of Bohr's magneton. Origin of colour of such paramagnetic ions in crystals. Discovery of a new photomagnetic effect.

(iii) Extension of Sir J. C. Bose's plant physiological investigations.

(1) As a student in the Cavendish Laboratory, he had seen C. T. R. Wilson develop his technique of employing the cloud chamber for photographing the tracks of ionizing particles. In Berlin he was given by Professor Regener the problem of devising a new type of Wilson chamber. This apparatus was used by Bose to photograph the tracks of recoil protons produced during the passage of fast alpha-particles through a hydrogen filled chamber. Bose was able to verify the formula given by Darwin for interpreting such collision effects. He also made some studies on delta-particles the discovery of which had just been announced by Bumstead. After returning to Calcutta, he with S. K. Ghosh, took photographs of recoil tracks of radio-active nuclei during the process of alpha-particle emission, and of the simultaneous emission of two ionizing electron tracks from a helium atom, due to collision with an alpha-particle. One photograph obtained by them was interpreted as showing the disintegration of a nitrogen nucleus. This photograph published in *Nature* (1923) elicited a warm letter of appreciation from Lord Rutherford. This line of investigation was temporarily interrupted by the death of S. K. Ghosh, as

the result of an accident. Subsequently, H. P. De obtained an early photograph of electron pair production by gamma-rays from mesothorium.

From 1938 he took up the study of tracks of ionizing particles using the photographic emulsion technique. His interest was aroused by a discussion with Bothe during the Science Congress Session of 1938, when Taylor had read a paper on the use of photographic emulsion for the study of cosmic radiation at high altitudes. Between 1939 and 1942 together with Biva Chowdhuri, Bose exposed a large number of photographic plates at Sandakphu, Phari Jong and Darjeeling, under different absorbing layers. They were able to prove that certain long curved tracks were due to mesons. For purpose of verification, a method of determining the mass of such track producing particles, by measuring their mean scattering and the mean grain spacing, was developed. The mean value of the meson mass found by them was $(216\pm40)m_e$, as compared to the subsequently determined value of the mass of mu-meson $(213\pm15)m_e$, following Powell's discovery in 1947 of two kinds of mesons, the π and μ mesons, with masses of the order of 214 and 290 respectively. It was also proved that the proton/neutron component of cosmic ray was largely responsible for meson production. With the departure of Biva Chowdhuri to England in 1945, this work was temporarily discontinued as it was felt that further investigations were only possible after the preparation of improved types of photographic emulsion. Later Powell in collaboration with Ilford & Co. was able to prepare such improved emulsions. It might be noted here that Powell was awarded the Nobel Prize for his investigations along this line.

When D. M. Bose joined the Bose Institute, two of his fellow workers, S. D. Chatterjee and M. S. Sinha, came over with him from the University College of Science. They have made significant contributions to the study of spontaneous nuclear fission, distribution of atmospheric neutrons at different altitudes, the influence of solar flare and associated geomagnetic phenomena on cosmic ray intensity, large cosmic ray bursts in Wilson chamber and the production of penetrating showers in lead and other materials.

In the Bose Institute, he has also collected a devoted band of workers in A. N. Banerjee, A. M. Ghosh, N. K. Ganguly, I. L. Chakraborty, T. C. Bhadra, N. C. Das and N. N. Biswas who have all had original contributions to nuclear physics or cosmic rays to their credit.

(2) In 1925, D. M. Bose became interested in the study of Werner's theory of co-ordination compounds, in which the central co-ordinating atom belonged to the para-magnetic group of elements. He proposed a rule for calculating the magnetic moments of such co-ordination compounds, which gave a criterion to distinguish between those compounds in which the co-ordination groups were bound to the central atom by covalent bonds, and those in which the groups were attached by electrostatic forces. Welo and Baudisch besides Sidgwick also attempted to interpret the magnetic susceptibilities of the complex compounds in terms of their chemical structure. Their views were formulated in the form of a rule, often known as Welo-Bose's rule. This states that the magnetic moment of a complex is the same as that of the atom with the same number of electrons as the central atom of the complex, counting two for each electron pair binding the central atom to the co-ordinated units.

Furthermore, Hund had shown how to calculate the magnetic moments of para-magnetic ions from the J values of the ions in the ground state. Excellent agreement was found between the theoretical and experimental values of the magnetic moment of ions belonging to the rare-earth group of elements. Hund's formula failed completely in the case of iron, palladium and platinum groups of elements. Bose showed that on the assumption that in ions of the iron group, the action of the neighbouring group of

ions and molecular groups quenched the contribution of the orbital quantum number to the ionic magnetic moment, the latter could be calculated from the S values of these ions. He, with his students H. G. Bhar, Sushovan Datta and others measured the magnetic moments of a number of compounds belonging to the palladium and platinum group of elements. The moment values for the ions of the iron group can be expressed by a formula, which is now known as Bose-Stoner's formula.

Next, investigations were taken up to measure the change in paramagnetic moment of ions belonging to the iron and rare-earth groups, due to light absorption. A new photomagnetic effect was discovered in collaboration with P. K. Raha. The effect as experimentally determined was, however, too small for satisfactory comparison with theory. Proceeding further with investigations on the origin of colour of paramagnetic ions in solution, it was established by him that the number of absorption bands was related to the l value of the absorbing ion, and the separation between the absorption bands due to an ion was proportional to the charge carried by it. He deduced a quantitative formula to express the separation between the absorption bands and compared it with the experimentally determined values. The assumption behind the formula was that the ground state of the paramagnetic ion is split up into $l+1$ levels in the electric field, due to the distribution of charged groups and polar molecules, a kind of Stark effect. In this line of investigation, S. Datta, M. Deb and P. C. Mukherjee participated.

A certain number of investigations on ferromagnetic oxides was carried out in his laboratory. D. P. Rai Chowdhury measured the gyromagnetic ratio in certain ferromagnetic oxides and found it to be nearly 2, which indicated that the spin value only of the d electrons contributed to the ferromagnetic moment. K. P. Ghosh measured the change in the electric conductivity of the iron oxide haematite when it passed from the ferromagnetic to the paramagnetic state. This was a qualitative verification of Heisenberg's theory of ferromagnetism. K. P. Ghosh and B. B. Ghosh measured the contribution to electrical conductivity due to the $4f$ electron in the fluorides of Ce^{+++}, Pd^{+++} and Nd^{+++} ions. With the help of a formula analogous to that developed by Wilson for semi-conductors, the value of AW, the change in energy level of the $4f$ electrons during conduction, was found to agree with the overall width of the multiple structure of these ions, as obtained from spectroscopic and magnetic measurements. An attempt was also made to measure the AW values of these ions from the change of specific heat of the fluorides at low temperature.

(3) After his assumption of the directorship of the Bose Institute, D. M. Bose began to interest himself in making the Institute the leading centre in the country for investigations in Plant Sciences, both in its theoretical as well as its applied aspects. He took it as a part of his responsibility to continue the plant physiological investigations for which the Institute was originally started by the founder. B. K. Dutt and A. Guha Thakurta collaborated with him in this project. As a result of these studies, he published a monograph entitled 'J. C. Bose's Plant Physiological Investigations in the Light of Modern Biological Knowledge'. He came to the conclusion that his predecessor's plant physiological investigations were mainly of a biophysical nature and required to be supplemented by a biochemical one, in which the biochemical processes intervening between stimulation and mechanical response in plants had to be established. He initiated the investigation regarding the source of energy of mechanical response in plant organs, including the spontaneous pulsation of leaflets in *Desmodium gyrans*, and the mechanism of the transference of energy released by carbohydrate oxidation to the motile plant organ. Basudeb Banerji started some investigations on the nature of the chemical mediator in the

propagation of excitation in the petiole-pulvinus unit in sensitive plants like *Mimosa pudica*. Tissue culture investigations have been started by B. K. Palit, for elucidating the conditions under which proliferation of differentiated cells in higher plants are changed into undifferentiated neoplastic growths.

D. M. Bose has also sponsored a number of applied investigations mainly in Plant Science subjects such as the following:

(*a*) Investigations on microbiological processes underlying the retting of jute and other fibres.

(*b*) Investigations on soil micro-organisms responsible for the production of antibiotic substances and for the fixation of atmospheric nitrogen.

(*c*) Identification of different virus strains in local commercial varieties of potatoes and the breeding of disease resistant strains by hybridization with primitive South American potatoes. The principal investigators in these three schemes have been H. K. Baruah, P. N. Nandi and A. Ganguli respectively.

(*d*) K. T. Jacob and his associates have been investigating the mutagenic action of X-rays, ultrasonic radiation, some chemicals and different antibiotics, the practical application of which has been directed to the fixing of new mutant strains in jute, cotton and oilseeds with improved economic characteristics.

(*e*) G. C. Bhattacharyya has opened up a new path in zoological research by his method of controlling the metamorphosis of amphibians like frogs from the larval (tadpole) state.

Thus, both as Professor of Physics in the University College of Science and as Director of the Bose Institute, D. M. Bose has trained, activated and inspired a generation of workers in his own lines and has possibly catalyzed many more.

In spite of his multifarious activities, D. M. Bose happens to be, more or less, a recluse. Since his earliest youth, books were his delight. His love of books and appreciation of Western music has grown since his student days in Cambridge. He was at one time a good walker and now he likes to spend his vacations amidst scenes of natural beauty, like Mayapuri, Darjeeling and the riverside bungalow at Falta. He has avoided both the limelight of public applause and the patronage of the powers that be. This may perhaps account for his somewhat belated election as General President of the Indian Science Congress. In his presidential address at Lucknow in 1953, he gave an illuminating account of the evolution of the living and the non-living matter and put forward some new evidence on the rôle of the unconscious mind in influencing genetic variations in organisms, suited for adaptation to altered environmental conditions.

Bose has not confined his activities within the narrow limits of his science. He always takes a keen interest in the progress of the social and cultural organizations of the country. As a member of the Governing Body, he is closely associated with the management of the City College and the Sadharan Brahmo Samaj. As Honorary Treasurer, he served the Viswa-Bharati for about 18 years. He was one of the sponsors of the Indian Physical Society and has served that body in various capacities. He is a life-member of the Indian Association for the Cultivation of Science, which he has served on many occasions either as a Vice-President or as a member of its Council. He has taken an active part in promoting the cause of the Indian Science News Association, of which he is now the President. For several years, he was the editor of its organ, *Science and Culture*. The editorial columns of this journal have frequently published his highly thoughtful and stimulating writings on various scientific and cultural topics. He is a Foundation Fellow of the National Institute of Sciences of India. He is also a member of the Asiatic Society

of Bengal, which he has also served on many occasions as Vice-president, Sectional Secretary, or member of its Council and of which he is now the President. He is a Fellow of the Calcutta University.

Dr. D. M. Bose has kept up his mental alertness in full strength. With advancing years his writings also bear stamps of mature wisdom and deeper thoughts born of accumulated experiences and intensive studies. May he live long in full activity to guide and inspire the rising generation with his wise counsels ! This is the earnest prayer of his numerous pupils, friends and admirers, who commemorate this occasion with the publication of this Volume.

BOSE INSTITUTE

PROGRESS OF RESEARCH FROM APRIL 1938 TO MARCH 1955

I. Introduction

The Bose Institute was founded on November 30, 1917, by Acharya Jagadish Chandra Bose. He was the first Director and continued to hold the office till he passed away on 23rd November, 1937. The Institute, as originally founded, concerned itself with carrying out the pioneering plant physiological investigations of the founder. Later on additional departments of physics and anthropology were started.

One of the first problems which the new Director, Dr. D. M. Bose, had to face in 1938 was to come to some understanding regarding the constitution of the Governing Body with the Government of India, from whom the Institute was in receipt of grants. According to the then existing constitution, the members of the Governing Body were appointed by the founder and served as life-trustees of the Institute. After prolonged negotiations the following principles were mutually accepted. The constitution of the Governing Body as a board of life-trustees, responsible for the management of the properties of the Bose Institute, remained unaltered. The day-to-day administration of the Institute was vested in a new body, called the Council, consisting of 12 members, including representatives of the Governing Body, the Government of India, the Central Legislature, and the Calcutta Corporation, and some outside scientists. The members of the Council hold office for three years and are eligible for re-election. A further principle accepted was that at intervals of five years the Government of India would nominate a Reviewing Committee, to report on the work of the Institute and to suggest changes, if any, in the working of the Institute, and to recommend the amount of Government of India grants, recurring and non-recurring, to be paid to the Institute. The first Reviewing Committee presided over by Dr. H. B. Dunnicliffe visited the Institute in January, 1940. A second Reviewing Committee with Professor Vallarta as Chairman visited the Institute in January, 1948.

Based upon the recommendations of the Dunnicliffe Committee, the Government of India forwarded to the Governing Body in 1942, certain proposals for modifying the existing Regulations and By-laws. After some correspondence, an agreed set of Regulations and By-laws was finally framed in 1945 and they came into effect from April, 1946. It was further agreed that the Institute, in addition to continuing its programme of basic researches in selected problems in physics, chemistry and biology, will also consider the practical applications of the results of such investigations to problems of agriculture, industry and medicine.

Following this new orientation, the Institute received for the first time in 1940 a grant-in-aid from the Department of Scientific and Industrial Research for the construction of a high powered ultrasonic generator. The late Dr. S. S. Bhatnagar, the then Director of Scientific and Industrial Research, was instrumental in securing this grant. Since then the Institute is receiving increasing amounts as grants-in-aid from different research-supporting organizations. In addition to materially adding

to the financial resources of the Institute, the grant-in-aid projects have also widened the scope of research activities in the Bose Institute.

Some of the projects taken up under such grants were ultrasonic radiation, nuclear disintegration, neutron generator, cosmic rays, mutagenic action of radiation for production of desirable mutants in economic plants like cotton, jute and oilseeds; cytogenetical and yield studies on cotton, cinchona, yeast and of their hybrids; isolation of new antibiotics from soil micro-organisms and their pilot-scale production; plant herbicides and weedicides; desulphurization of coal, impregnation of bleached jute fibres with synthetic resin, etc.

At present the relative contributions to recurring grants from various sources, like the Central Government, grants-in-aid, and from invested funds, are as four to three to one. From time to time the Institute receives non-recurring grants from the Government of India as well as from the Trustees of J. C. Bose Trust No. 1.

The scope of research to be undertaken in the Institute was defined by the founder as 'The fuller investigation of the many ever-opening problems of the nascent science which includes both Life and Non-life.' In particular, investigations are to be undertaken on the different aspects of plant life with a view to discover the fundamental unity in the life processes underlying the diversity of their manifestations in plants and in animals.

The work of the Institute is now carried on mainly in the following departments: (i) Physics and Biophysics, (ii) Organic and Physical Chemistry, Plant Biochemistry and Chemistry of Plant Products, (iii) Plant Physiology and Genetics, (iv) Microbiology.

II. Progress of Research

In the following account of the research activities of the Institute since 1938, we shall first describe what has been done in the Institute to continue the three principal lines of investigation with which the founder had been associated. These were (i) study of the quasioptical properties of short electromagnetic waves in the region of centimeter wave-length, (ii) study of the similarity of responses in the Living and the Non-living, and (iii) study of the similarity of responses in plant and animals. Of these the last interested J. C. Bose from 1906 onwards, and for the study of which the Institute was principally founded. In course of its recent development the work of the Institute is becoming more and more centred round the plant sciences, including microbiology.

(i) *Short electromagnetic waves.*—Continuation of this line of investigation has been taken up only very recently in the Bose Institute. A comparative study is being made of the modern microwave apparatus, capable of generating continuous and reasonably monochromatic radiation, in the region of 3 cm.–1 cm. wave-lengths. This has been undertaken with a view to find out how far the simple apparatus designed by J. C. Bose can be modified to make it suitable for precision investigations in this region. As has recently been found out, the technique of paramagnetic resonance using centimeter wave-length of e.m. radiation has interesting applications in the study of free radicals present in many living tissues as well as in many organic compounds. This will be a useful extension of D. M. Bose's paramagnetic investigations.

(ii) *Responses in the Living and the Non-living.*—This subject has been dealt with in the last chapter of the monograph published in 1945 by D. M. Bose, and

entitled 'J. C. Bose's Plant Physiological Investigations in relation to Modern Biological Knowledge'. It was shown that the electrical responses obtained by J. C. Bose on mechanical stimulation of tin-wire dipped in very weak electrolytes, etc. belong to the class of responses observed by Lillie with his iron-wire model and Bredig with large mercury drop covered with a slightly alkaline solution of hydrogen peroxide. All these electrical and mechanical responses are associated with the formation and breakdown of an oxide layer at the surface of separation between a metal and an electrolyte. This non-conducting layer enables the maintenance of an electric potential between the metal and the electrolyte. In his presidential address before the 41st Session of the Indian Science Congress, D. M. Bose took as his theme the Living and the Non-living. He recalled that fifty years ago J. C. Bose had published a monograph entitled 'Response in the Living and the Non-Living,' in which he had made the first attempt to subsume, under common physiological concepts, the response to stimulation in living and non-living systems. After nearly fifty years, with the growth of servo-mechanism and radio communication, a new discipline called cybernetics has grown up which proposes to subsume the receptor, effector and control mechanisms in living and non-living systems under another set of physiological concepts. J. C. Bose may thus be considered a pioneer in cybernetics.

Bioelectric potentials.—A promising line of investigation was started in 1939 by Dr. B. K. Bagchi, a J. C. Bose Fellow of the Calcutta University on the study of spontaneous electric potential variations given out in certain cortical regions of the human brain. The first electro-encephalographic instrument used in this country was constructed locally in 1940 according to Bagchi's design, and some promising lines of investigations on local human materials were started. Due to the investigator's return to the U.S.A. after the outbreak of second world war in the Pacific Ocean, the investigation had to be terminated. Recently the study of the transmission of action potentials along the pulvinus-petiole region of *Mimosa pudica* following stimulation, has been taken up, using D.C. amplifying circuit and fast recording galvanometer. This line of investigation has made some progress in Japan.

Bioelectric potential developed at the growing tip of germinating seed, between the two sides of skins of apple and other fruits during ripening were also studied.

(iii) *Plant physiology.*—In his monograph on 'Plant Physiological Investigations, etc.,' D. M. Bose showed that in studying the behaviour of the plant as a responsive organism, J. C. Bose worked chiefly with biophysical concepts, *viz.* the process of stimulation, its transmission through plant connective tissues, the resulting mechanical response, like growth, tropic and nastic movements, and other kinds of mechanical responses to artificial stimuli. J. C. Bose was the first to establish that all processes of transmission of stimulation in plants were accompanied by the propagation of a current of excitation and that all mechanical responses have electrical correlates. Further even when the mechanical response is made or becomes ineffective, the electrical correlate is always there.

During recent years the view is gaining ground that all the activities of a living organism, namely growth, reproduction, homeostatic control and response to external stimuli, are based upon a series of inter-related biochemical processes activated by systems of enzymes, which are accompanied by changes in the free energy of the system. Many of the plant response phenomena are now being studied in the Bose Institute from this point of view. Some of the results are given below:

The source of energy of mechanical pulsation of young lateral leaflets of *Desmodium gyrans (Leguminosae)* was found to be due to the oxidation of carbohydrate synthesized during daytime by photosynthesis. In another plant *Oxalis acetosella* (*Oxalidaceae*) similar but much slower rates of pulsation were observed. In semi-mature leaflets, in both specimens, the pulsations cease at night; if however the cut stems with leaflets of these plants are placed in dilute glucose solutions, the pulsation continues day and night. The anatomical structures of the pulvini of these two plants, belonging to two different orders, show a great deal of similarity, and can be cited as an instance of parallel evolution.

Results of investigations carried out with the *Mimosa* group of plants and with allied groups make the assumption plausible that movements like closure of leaves and decrease in amplitude of response of *Mimosa* pulvinus with the onset of darkness, are brought about by the depletion of carbohydrate reserves. Both in *Mimosa* and in *Desmodium,* the depletion of carbohydrate reserve leading to stoppage of pulsation and closure of leaves and folding of pulvinus in dark, is most marked in the younger leaves.

In continuation of J. C. Bose's other investigations with *Mimosa* the following types of investigations are being pursued:

(*i*) The question whether a chemical factor is involved in the mechanism of transmission of excitation in the stem and petiole of *Mimosa* has been thrown up by Ricca's discovery of a chemical mediator present in an aqueous extract from macerated stem of *Mimosa.* In the beginning there was a lot of controversy about the significance of Ricca's observation. The discovery of a substance like acetyl choline which chemically mediates the transmission of electrical stimulation between the junction of a motor nerve and motor muscle has stimulated efforts for the isolation and structure determination of the chemical mediator present in *Mimosa* tissue. The Institute has been working on this problem for over nine years without having been able to isolate the active substance in a pure state and to establish its chemical structure.

The second problem studied is the nature of the contractile mechanism in the pulvinus of *Mimosa.* Investigations, carried out in the Bose Institute as well as in Japan and in Canada, have shown that the cells in the contractile pulvinus contain large vacuoles, the dimensions of which change during cellular contraction, resulting in an expulsion of sap. The curve of expulsion and intake of water with time from a pulvinus during contraction and recovery has recently been determined in the Institute. The following results have been obtained. The contraction takes place very rapidly while the recovery may extend over ten to fifteen minutes. The volume of water expelled from the pulvinus through the connecting petioles during contraction is significantly smaller than that absorbed during recovery. It appears that during contraction a considerable volume of water escapes through certain openings which are formed in the semi-permeable walls enclosing the contractile cells; these openings close up during recovery. There is a very interesting analogy in the mechanism of expulsion of water from a contractile amoeba following stimulation, in which a reduction in the vacuolar volume occurs and certain openings are formed on the cell-walls through which water is expelled during cellular contraction. The time of recovery is much larger. It is assumed that during recovery the openings on the cell-surface close, and the water is reabsorbed across the latter by the ordinary diffusion process.

It has been found that these contractile vacuoles in *Mimosa* pulvinus are stainable by safranin and other stains and contain tannin sacs. They appear to be identical with J. C. Bose's active substance. Whether the tannin-like substance and other solutes extracted into the cytoplasm during contraction constitute the irritability substance remains to be determined.

J. C. Bose had drawn attention to the reported presence of a highly stainable material present in the breast and skeleton muscles of birds like falcon and pigeons, the distribution of which has been found proportional to the activity of the muscle, and which J. C. Bose assumed to be analogous to his active substance. The stainable substance, present not only in animal muscles but in heart and kidney as well, has recently been identified with mitochondria-like bodies; they contain a chain of related enzymes taking part in the Krebs' cycle. Their presence in the pulvini of plant contractile cells has been recently established both in the Institute and by other workers.

(*ii*) *Photosynthesis.*—The mechanism of photosynthesis in the aquatic plant *Hydrilla* was the subject of detailed study by J. C. Bose and N. C. Nag. It was observed by them that carbon dioxide as well as malic acid dissolved in the aquatic medium can be utilized for carbohydrate synthesis by this plant. Recent studies have made it probable that in certain class of plants, malic acid forms an intermediate breakdown product of the stored carbohydrate. During the dark period the formation of the malic acid in the Krebs' cycle is said to be associated with the dark fixation of carbon dioxide by such plants. The rôle of malic acid in the synthesis and degradation of carbohydrates in *Hydrilla* is being studied by the method described in the following paragraph.

The *radioactive tracer technique* is being employed for investigations of the metabolic changes which lead to the formation of carbohydrates and other energy-rich compounds, like fats and proteins, as well as their breakdown products during respiration. Radioactive isotopes like C^{14}, P^{32} and S^{35} are being employed for this purpose. The auxiliary apparatus for such investigations such as paper chromatography, autoradiography and use of G.M. scintillation counters have been developed in the Institute laboratories.

In recent years semi-large scale cultures of autotrophic unicellular algae like *Chlorella*, *Scenedesmus*, and blue green algae, are being carried out, as a method for economic utilization of solar energy for production of valuable food materials like fats and proteins. This line of investigation has been started in the Bose Institute. Collections are being made from local sources of thermostable green algae better suited for cultures in semi-tropical environments of this country.

III. Other Plant Physiological Investigations

We conclude this section with a short review of other plant physiological investigations which have been carried out since 1938.

(*iii*) *Vernalization.*—Investigations were carried out by B. K. Kar (1938–45) on the effect of pre-sowing thermal treatment and post-sowing photo-period treatment in inducing earliness of flowering in economic plants. There is a difference in the response of Indian wheats to cold temperature vernalization compared to that of wheat grown in cold and temperate climates. This has been found to be due to difference in the post-sowing photo-stage conditions.

In tropical countries the wheat plant has to grow under short-day conditions

and though of temperate origin it has to complete its life-cycle under same conditions. Therefore the effect of pre-sowing vernalization could not become effective under prevailing short-day conditions. If, however, such plants are grown under long-day conditions significant earliness of ear emergence is induced, while short-day condition retards the same. Even a few days of post-sowing long-day periods induce marked earliness of ear emergence. In certain varieties of wheat (I.P. 4 and 52) post-sowing long-day treatment leads to earliness of flowering by 24 days over controls, while in oats (I.P. 1) similar treatment brought about an earliness of flowering of 43 days. Detailed studies with different varieties of Indian wheat showed that cold temperature effect was of a varietal nature.

Experiments of a similar nature were carried out on both *Aus* and *Amon* varieties of rice. Both pre-sowing heat and cold treatment followed by post-sowing light treatment were tried. In certain varieties pre-sowing heat-treatment resulted in earliness of flowering, while in others no appreciable effect was noticed. Pre-sowing cold treatment gave no significant result.

The effects of post-sowing photo-periods showed a significant earliness under short-day treatment. The seedlings treated to short-day conditions of 8–9 hours photo-period after transplantation showed an earliness of flowering in some cases of 20 to 25 days.

Pre-sowing treatment of alternate moistening and drying and post-sowing light treatment on drought resistance and earliness of flowering have been studied with jute.

(*iv*) *Physiology of development and ripening of some Indian fruits.*—These investigations were carried out by J. K. Chowdhury, B. K. Kar and H. K. Banerjee (1938–42). They included studies on the effect of oxygen concentration on the respiratory activity of storage-organs of plants, physiology of development and ripening in mango and guava and evolution of volatile products in relation to respiratory activity of the fruits. The effect of ethylene gas in inducing changes in mango at different stages of its growth, biochemical changes which accompany senescence in mango, anaerobic glycolysis, and the enzymes responsible for the development of senescene were investigated.

(*v*) *Carbohydrate metabolism in date palms.*—The source of sugar excreted from incised date palm has been investigated. The nature of the solid content of sap consisting of sugar (85%) and of proteins was determined. The starch and sugar content of both leaf and tree-core has been determined. It was found that even in almost totally defoliated date palm the sap could be collected for a considerable time without the tree showing much ill effect. The carbohydrate content of the tree-core and the enzymes responsible for the production of the soluble sugar exuded with the sap were studied. Further investigation with application of modern technique on the enzymes involved will soon be taken up.

(*vi*) *Plant auxins.*—A number of studies has been made on the effect of heteroauxin like indole acetic acid (IAA) and indole butyric acid (IBA) on growth, tropic and nastic movements, adventitious root formation and tissue respiration of plants. Some of them are described below:

Studies on adventitious root formation due to auxin treatment of stems have been made chiefly with *Impatiens*. The effect observed has been interpreted on the hypothesis that the auxin mobilizes a growth factor, present in the plant, to the treated region.

Practical application of this method has been made for the vegetative propagation, by means of auxin treatment of cut stems of mango and of cinchona. Semi-large scale trials were made of the latter at the cinchona plantation, Mungpoo. The effect on root growth, by application of auxin at the basal and terminal portion of the primary root in groundnut plant, has been studied.

Auxin as weedicides.—In 1946 an investigation was commenced by B. K. Kar on the effect of spraying broad-leaved weeds like water hyacinth, *Lemna*, *Pistia*, *Salvinia* with different concentrations of Methoxone, a derivative of 2:4-dichlorophenoxy acetic acid (2:4-D) supplied by the Imperial Chemical Industries. These auxins were known to produce in small concentrations morphogenic effects on plant organs; they have been found to be very efficacious in stronger concentrations as weedicide against these broad-leaved weeds.

In 1953 an Indian Council of Agricultural Research (I.C.A.R.) grant was received for investigation of the economic feasibility of controlling weeds growing in cultivated fields by the newer types of weedicides obtainable either from research laboratories (like the Bose Institute, the National Chemical Laboratory) or from commercial firms. The weedicides tested were Cornox, Dicotox, Fernoxone Agroxone, T.C.A., 2-4-5-T and Crag Herbicide. The conditions under which the different weedicides could be usefully employed without injuring the economic plants have been investigated. The Crag herbicide is found to possess some advantageous properties inasmuch as it does not affect the established plant, but controls the germination of weed seeds. The physiological nature of the control effected, and the intensification and destruction of the action of the weedicides by soil micro-organisms are being studied.

(*vii*) *Tropic effect.*—The tropic response on plant stems has been shown to be due to two factors—an electric polarization of the perceptive layer of the stem (discovered by J. C. Bose) and the chemical effect of an auxin diffusing from the stem-tip, with differential growth effects on the two polarized ends of the stem, either transverse or longitudinal. The effect of cutting the stem-tip resulting in production of electric polarization without production of curvature or of growth has been studied.

(*viii*) *Respiratory effects.*—Following the report of an observation on the effect of auxin on the respiration of *Avena* coleoptiles submerged in different nutrient solutions, the effect of IAA on the respiration of leaflets of *Desmodium gyrans*, when its cut end is dipped in different substrates containing a very small amount of IAA, has been studied. It was found that only with a malate solution, the IAA enhanced the respiration by 50 per cent.

Subsequently using Warburg's manometer, the effect of various concentrations of IAA on submerged *Avena* coleoptiles has been studied in continuation of the investigations of Bonner, Thimann and others. It is planned to isolate the respiratory and other enzymes present in *Avena* coleoptiles, and to observe the effect of IAA on them separately. This will be started after the completion of a cold temperature laboratory for plant enzyme investigations.

(*ix*) *Plant tissue culture.*—Investigations have been going on since 1940 on *in vitro* culture of both organs and undifferentiated tissues of plants. For root cultures, cucumber and tomato roots have been used. The minimum requirements of amino acids for growth of excised tomato roots have been studied. Some amino acids have stimulating effect on growth, and others inhibitory. Attempts were made

in vitro to culture tissues by IAA treatment of small fragments of carrot grown in 2% sucrose with White's nutrient medium, liquid or semi-solid.

Under certain conditions of culture, growth could be maintained with cambium fragments of carrot in White's liquid medium. Callus growth was observed on the cut surface of cambium after 2 or 3 transfers, and this growth could be continued up to 4 months after which it appeared to cease. Sometimes the presence of secondary phloem and xylem, which grow at the expense of cambium, is rather a hindrance to the development of callus tissue.

Gall Tumor.—Studies have been commenced on the formation of crown gall tumor on certain plants by inoculation of *Agrobacterium tumefaciens*. The plant *Antirrhinum* has been found to be a new host for growing such tumors. Investigations are made chiefly with sunflower and *Bryophyllum*.

At present attempt is being made to produce bacteria-free tumor tissue by keeping the whole plant or only the bacteria infected portion, under conditions of temperature and humidity, which will kill the injected bacteria and not injure the host plant. Various methods of thermal treatment have been tried without complete success.

(*x*) *Growth and nutritional studies on plants*

Jute.—One of the problems which have been studied is the cause of 'dieback' effect in jute plants. A similar effect is observed in mulberry plants also. Sand culture method has been employed to study the effect of trace elements, of inorganic nitrogen and phosphorus compounds in inducing or preventing 'the dieback' effect.

This disease appears in both jute and in mulberry just before the monsoon season and disappears with the onset of rains. Mulberry plants grown in the plains under different manurial treatments show the effect, while plants grown at comparatively higher altitudes of Kalimpong and Mysore, do not show the effect. It seems that temperature and humidity are causative factors. Whether it is a physiological disease or due to a virus infection has not been definitely established.

Cinchona.—Investigations using both sand- and water-culture methods were made to determine the mineral requirements of *C. Ledgeriana*, and of the possibility of its being acclimatized for growth in the lower altitudes of West Bengal. For some time the investigations were carried out in an air-conditioned glass-house to determine the best conditions for growth. J. C. Bose's crescograph and sphygmograph were employed to measure the diurnal variation of longitudinal and diametric growth. Similarly investigations were made to find out if any relation existed between root respiration and longitudinal growth. It was noticed that there is a diurnal variation in longitudinal growth, the growth being greater during the night. In addition there is another periodicity in growth, associated with the opening of the apical bud, when growth is accelerated. It is probable that with the opening of the apical bud there is an increased transport of auxin from the growing region downwards. It was also found that there was periodicity in root respiration which coincided approximately with the opening of the apical bud and the correlated acceleration of longitudinal growth.

In *Dahlia* there is a diurnal variation of longitudinal growth which occurs in pulsations of alternate expansions and smaller contractions. In addition periodic increase in growth similar to that observed in *Cinchona* has been observed with *Dahlia* and sunflower.

IV. Cytogenetics and Plant Breeding

Experiment on cotton breeding was started at Falta in 1941 by Dr. B. K. Kar with Dacca and Desi types. They were found to be poor yielders and susceptible to disease and the experiment was abandoned.

With the appointment of Dr. K. T. Jacob, first as Research Fellow and later as Head of the Department of Botany, systematic experiments were carried out on effecting improvements in cotton, jute and oilseeds, by selection, hybridization, and by production of radiation-induced mutants with improved economic characters. The radiations employed were ultrasonic, X-rays, γ-rays, neutrons, and β-rays from radioactive isotopes which are specifically absorbed in plant nucleus. The most systematic work has been done with X-rays; some new effects have recently been observed by using radioactive isotopes like P^{32}, S^{35}, etc.

(*i*) *Cotton.*—A grant was received from the Department of Agriculture, West Bengal, during the period 1945–54. In the beginning, attention was directed to the collection of stabilized long-stapled and/or sturdy strains of cotton from Lyallpur and Coimbatore districts. These parent strains numbering about 30 have been maintained, and different hybrids were made by back and cyclic crossings. From the 600 hybrids produced, a few which showed promising characters were grown on a semi-large scale. Selections were based on the possession of all or some of the following characters: earliness of flowering, lint length, ginning percentage, disease resistance, and yield. The crosses which are being maintained show many of these characters. Some of them are found to be better suited for cultivation under different environmental and soil conditions other than those found in the deltaic area of Bengal.

One F_3 cross between CO2 × 4F has produced a fuzzless mutant, which if stabilized would have distinct economic advantage. In subsequent generations the character appears to be segregating, leading to the production of gradation from total fuzzlessness to loss of this character.

X-ray irradiation of some varieties has resulted in higher yield and greater ginning percentage, but no increase in fibre length. These types are now being stabilized.

(*ii*) *Jute.*—The scheme was financed from 1946 to 1955 by the Indian Central Jute Committee. In 1942 cytogenetical investigations were made on 4 types of *Corchorus olitorius* and 5 types of *Corchorus capsularis*. From the following year, X-ray irradiation of jute seeds were tried with D-158 and D-386 (*capsularis*) and Chinsura Green (C.G.) and R26 (*olitorius*). Of these R26 was found to be the most susceptible to X-ray treatment. With this variety, significant differences in heights and basal diameters were found from the beginning between progenies of treated and control plants. As a result of irradiation and selection from progenies of irradiated seeds of R26, a mutant has now been obtained to which the name Tall Mutant (T.M.) has been given. The maximum height attained by such mutant was 22 ft. and the basal diameter, 1·5″. The average height of T.M. in one set of measurements was found to be 2′ 8″ greater than that of the control, while there was a slight increase in basal diameter by 0·1″.

The Tall Mutants are characterized by (*i*) enhanced vegetative activity leading to greater height and basal diameter, (*ii*) higher fibre yielding capacity by as much as 50 per cent over the controls, (*iii*) deep scarlet colour of leaves and stems when

mature and (*iv*) slightly better fibre quality, but no appreciable change in the chemical composition of the fibre.

Isotope treatment.—Recently seeds of R26 were steeped in weak solution of $Na_2HP^{32}O_4$ (radioactive). On germination a few plants were found to possess the characteristics of the T.M. and some of Chinsura Green (C.G.). Such an effect has not been observed with X-ray radiation. In the second generation of plants grown from these T.M. seeds, there has been a segregation of colour, *viz.* plants similar to C.G., R26, and T.M. were found. It would appear that both C.G. and T.M. were derived from R26 by mutation.

Other interesting modifications which have been achieved by X-ray treatment are (1) an early flowering mutant and (2) plants with bifurcated stems starting right from the bottom. The latter has not been stabilized; probably it is a physiological effect common to both the varieties, *olitorius* and *capsularis*. The percentage of changes produced is proportional to the duration of exposure.

(*iii*) *Oilseeds.*—A grant is being received from the Indian Central Oilseeds Committee since 1950, for production, by X-ray irradiation, of mutants of *Sesamum* and *Brassica*, with higher yields of oil.

Sesamum.—In both *Sesamum* and *Brassica*, some varieties of plants are found to be susceptible to X-ray irradiation, leading to an increase in number of fruits per plant. In some cases in *Sesamum* the increase has been up to 200 per cent in X_1. In X_2 there is segregation but the average yield per plant is still much higher than that of the control. There is some difference in the appearance and chemical composition of the oils obtained from the mutant and the control plants. Continuation of the cultivation of the mutants for at least three more generations will be necessary before the mutants can reach stability.

Brassica.—Similar increased yields from progenies raised from irradiated seeds have been noticed with different varieties of mustard. More significant results from irradiation were obtained a year later with *Brassica* than with *Sesamum*. A few more years of propagation of plants raised from irradiated seeds will be necessary before the yield characteristics of the mutants are known definitely.

V. Physics

When Dr. D. M. Bose joined the Bose Institute in 1938, the Department of Physics had men like R. C. Mazumdar and A. K. Datta. S. D. Chatterjee, M. S. Sinha, and Bibha Choudhuri accompanied him from the Science College. They were later joined by B. B. Ghosh and N. K. Saha. Out of these only M. S. Sinha has retained his connection with the Institute; most of the others are now occupying distinguished positions in Universities and elsewhere. The physical investigations carried out in the Institute can be grouped as follows: (*a*) Theoretical Physics, (*b*) Paramagnetism, (*c*) Ultrasonics, (*d*) Cosmic Radiation and (*e*) Nuclear Physics.

(*a*) *Theoretical Physics.*—During the period 1938–1943, R. C. Mazumdar with fellow workers including Bibha Mazumdar, S. Gupta and others carried out varied theoretical investigations on astrophysics, stellar structure, meson fields, scattering of charge particles, statistical mechanics, etc. With his departure, the department of theoretical physics was closed.

(*b*) *Paramagnetism.*—The investigations were a continuation of those initiated by D. M. Bose while in the College of Science. These were on the origin of absorption

band and of the fine structures exhibited by paramagnetic ions of the iron group in solution and in hydrated crystals. An empirical formula with one undetermined constant was deduced by him, which satisfactorily accounted for the number and mean wavelengths of the absorption bands. These absorption bands are due to transitions from the ground level to the excited 1-levels (1-orbital quantum number) into which the degenerate ground state of the ion is split up in an electric field of cubic symmetry. The fine structure could be partially accounted for by the additional splitting of the D and F levels by superposed fields of trigonal symmetry, as discussed by Van Vleck.

Microwaves of wave-lengths between 1 cm. and 3 cm. are being recently used to measure the splitting up of the fine structure of the levels in a magnetic field. This magnetic resonance method will soon be used in the Institute.

(*c*) *Ultrasonics*.—A. K. Datta spent a year in Prof. Debye's laboratory in Berlin to learn the technique of production of ultrasonic radiations in liquids, and the optical methods employed in determining their velocities and absorptions. He found some evidence of dispersion of ultrasonic waves in water and in other liquids. Datta also undertook some theoretical investigations correlating the compressibility, absorption, and dispersion of ultrasonic waves in liquid media. After his return to the Bose Institute, an apparatus similar to that used by him in Berlin was constructed in the Institute workshop.

A number of investigations has since been made on the variation with concentrations of the velocity of ultrasonic waves in electrolytic solutions, in some of which the variation in velocity with concentration behaves anomalously. It is surmised that there is a relation between the compressibilities of these electrolytes and their viscosities. A theoretical investigation was made to correlate the viscosity of liquid, with the cohesive force between molecules, and other molecular constants.

Variation of velocity of ultrasonic waves in different organic liquids and their mixtures has also been studied, leading to the discovery of certain minima and maxima in them. These results have been interpreted quantitatively in terms of the theories of molecular fields developed by Debye, Kessom, and London.

In 1941 the Institute received a grant from the Council of Scientific and Industrial Research (C.S.I.R.) for the development of a powerful ultrasonic generator. During the war years it was necessary to construct locally all the essential components, consisting of a large demountable triode valve, and oil diffusion pump for evacuation of the valve, cutting of x-cut quartz plate oscillators out of locally available quartz crystals. Difficulties were encountered in the working with the triode valves made up of metal and glass parts cemented together with resins and waxes. The second difficulty was in the construction of large low-frequency oscillators, which were made by cementing together a mosaic of matched quartz oscillator plates between two steel plates. During this period some practical applications were made of ultrasonic radiations as bactericidal, mutagenic and emulsifying agents.

The question of mechanism of absorption of ultrasonic radiation in liquid is now being discussed theoretically from a new standpoint. During the propagation of ultrasonic radiation through a liquid, a part of the radiation pressure energy along the wave-normal is converted by viscous forces into hydrodynamic flow. Cady has devised an apparatus by which the radiation pressure and the momentum due to hydrodynamic flow can be measured separately. An apparatus similar to

that used by Cady has been made in the workshop. Investigations chiefly with liquids showing anomalous large absorption are being undertaken.

(d) Cosmic radiation.—Prior to 1938 R. Ghosh had measured the east and west asymmetry in cosmic radiation at Darjeeling. This work came to an end after Ghosh's departure. Since then investigations on cosmic rays have been carried out by the following methods: (i) photographic emulsion, (ii) pressure ionization chamber, (iii) cloud chamber and (iv) counter telescopes.

(i) *Photographic emulsion method.*—The genesis and the main results of the investigations have been described in another place. Ilford New Halftone plates exposed to cosmic rays were found to contain some long curved tracks which could not be due to either fast protons (which show very little scattering) or due to electrons (to which the given emulsion was not sensitive). It was assumed that these tracks were due to mesons which like protons are singly charged, and consequently the equality in mean grain spacing along both these particle tracks was due to equality of their velocities. The photographic emulsion was calibrated in terms of energy, range, and mean grain spacing along tracks of recoil protons in the hydrogen containing emulsion when exposed to neutrons from radium-beryllium sources. The other independent observation made was the measurement of the mean scattering along the meson tracks. By this method for the first time the meson mass was determined from observations made on photographic emulsion and it turned out to be that of μ-mesons. By exposing photographic plates at different altitudes, and at each altitude under different absorbers like water, paraffin and lead, the conclusion was reached that the multiple tracks produced by nuclear disintegration in the emulsion were principally due to the proton-neutron component of the cosmic rays. In a subsidiary investigation a comparative study of the mechanism of formation of latent images in silver halide grains by means of light and by ionizing radiations was made. It was found that similar to the calculations of Webb and others, which showed that it required the absorption of several hundred light quanta to make the silver halide grains developable, an equivalent amount of ionizing energy has to be transferred from fast ionizing particles to make the grains developable.

The investigations, which were suspended in 1944, were again taken up with the new types of nuclear emulsions introduced by Ilford and Kodak. Some of the electron-sensitive plates were sent up by meteorological balloons to heights of about 40,000 ft. The investigation had to be temporarily closed down due to the difficulty of recovery of the exposed plates and the resulting general blackening of the sensitive emulsion. At present effort is being made to coat glass plates locally with emulsion imported in bulk. A large number of bursts and tracks of lengths up to 3,000 μ was obtained. In some plates loaded with uranium compounds and exposed to slow neutron, besides binary fission tracks, a ternary fission was observed in which the masses of the three particles were of the same order. It was calculated that the ionization energy of the tracks was much larger than the energy of fission of uranium nucleus and must be due to the collision of a U^{238} nucleus with non-ionizing cosmic ray particles of high energy of the order of 10^9 eV.

Proportional counter.—Large cylindrical boron trifluoride filled proportional counters were used to determine the neutron flux at different altitudes up to 7,000 ft. By this method only the number of slow neutrons and not the energy distribution of fast cosmic-ray neutrons was measured. Using neutron scintillation counters it is proposed to measure the atmospheric neutron energy spectrum.

(ii) *Pressure ionization chamber.*—From 1947 to 1952 intermittent records were kept of the continuous variation of cosmic ray intensity by means of a steel ionization chamber of 4·5 litre capacity filled with argon gas at 11-atmosphere pressure.

Increase in cosmic ray intensity was recorded on 25-1-49 followed by the usual fall of intensity; this was associated with severe sunspot activities. Increase in cosmic ray intensity was again observed on February 20 and 22 which was followed by a large magnetic storm of the sudden commencement type and a corresponding depression of cosmic ray intensity. This event coincided with the movement of a large group of sunspots which were visible on the sun's surface from February 14 to 27, 1949. In a counter-telescope arrangement with 10 cm. lead between counters, which was being used to determine the absorption of cosmic rays in different thickness of lead absorber, a 100 per cent increase of counter frequency was observed between 1 and 2 p.m. on February 28, which preceded by an hour and half the eight per cent increase in ionization current in the above-mentioned unshielded ionization chamber.

In 1950 another solar disturbance occurred between 7 and 11 August, corresponding to the solar flare observed on August 8. A sudden rise in cosmic ray intensity was observed on the same day with the ion chamber recorder. This was followed 24 hours later by a severe magnetic storm of the sudden commencement type. After 1950 the sun has been passing through a quiescent phase on the whole.

Another large cylindrical pressure ionization chamber (volume 30 litre filled with argon at 50 atm. pressure) has been set up for continuous record of cosmic ray intensity. The average ionization current through the chamber is compensated by an arrangement similar to that used by Compton for the purpose. To avoid fluctuations of current due to fluctuations in atmospheric radioactivity the chamber is surrounded by lead bricks and iron bars. This apparatus will be useful in recording the diurnal and seasonal variations in cosmic ray intensity, in addition to recording of large variations due to extra terrestrial causes.

Small pressure-ionization chambers of different volumes, enclosed in walls of different materials and filled with different gases (like argon, hydrogen) at various pressures, are connected to fast recording photographic arrangements. Continuous records of size frequency distribution of ionization bursts produced in the chamber have been made for 200 hours in Calcutta. The apparatus is now working for about a year in Darjeeling. Over, above and round the chamber, lead and paraffin blocks of different thicknesses are placed. Different arrangements of coincidence counter circuits are being employed to record on the same film the simultaneous occurrence of extended and narrow air showers and of cosmic particles, ionizing and non-ionizing, which are stopped in the chamber and give rise to heavy local bursts only.

The experimental arrangement is being continuously improved so as to enable the obtaining of precise information on the fragmentation burst distribution which originates from wall of the ion chamber. S. D. Chatterji and I. L. Chakraverty have been associated with this work.

(iii) *Wilson cloud chamber.*—The first large cloud chamber of 30 cm. diameter and triggered by a counter telescope circuit was made in 1941 by R. L. Sen Gupta and M. S. Sinha. This work is now in charge of M. S. Sinha with N. C. Das and Nilima Bose as collaborators.

Some of the important results obtained are:

(i) Determination of the rate of emission of penetrating particles in different thicknesses of lead and iron.

(ii) Nuclear disintegration by a non-ionizing cosmic ray particle resulting in the emission of four heavily ionizing particles.

(iii) Occurrence of a heavy ionization burst in the gas volume of the cloud chamber resulting in the emission of a very large number of ionizing particles, some of which are stopped in a 2·5 cm. lead plate and others give rise to cascade showers.

(iv) Photograph of an explosive shower of a mixed type containing both soft and penetrating particles generated in one of the lead plates.

A larger rectangular cloud chamber with 11 plates of $\frac{1}{8}''$ thickness of Pb has been constructed. This was used in Calcutta and is now being used in Darjeeling for the study of nuclear interaction of N-particles in a 15 cm. Pb absorber placed above the chamber. Some interesting photographs of disintegration of V^0 particles and of a K-particle have been obtained.

A small cloud chamber inside the field of a large electromagnet is now ready for use. It will be first used to determine the ratio of positive and negative mesons which stop inside the cloud chamber.

Delayed coincidence circuits are being used for the study of mean life of positive and negative μ-mesons, in different absorbers like Al, Pb, S and C. The resolving power of the delay circuit has been further improved for more accurate determinations of the mean life of negative μ-mesons in absorbers with larger nuclear charges.

(*e*) *Nuclear Physics.*—The Institute now possesses Ra-Be sources of total strength 160 mc., and also procures from time to time α-particle emitting sources like polonium. A number of investigations on artificial radioactivity induced by neutron and α-particle bombardment of different materials, was undertaken from time to time by N. K. Saha and S. D. Chatterjee and their collaborators. These include the effect of bombardment of F^{19} by α-particles leading to alternate reaction F^{19} (α, p) Ne^{22} and F^{19} (α, n) Na^{22} and their resulting radiations and nuclear isomerism in Br^{80} produced by bombardment of bromine with slow neutrons. Some studies were made on the γ- and β-coupling in some radioactive isotopes. Radioactive isotopes of iodine have been utilized to follow the exchange of iodine ions between covalent and co-ordination bonds within one and the same complex zone. There is no essential difference between normal and co-ordination covalency. Radioactive bromine has been used to prepare a number of organic bromo-compounds in which radioactive bromine has been introduced in both aliphatic and aromatic molecules. Detailed studies have been made on the two isomers of radioactive bromine.

S. D. Chatterjee devised several fast recording arrangements for measuring the ionization due to heavy particles including neutrons produced by reaction with primary cosmic rays. For detecting the latter he employed large volume proportional counters filled with BF_3 gas and with the inner wall lined with a thin layer of boron. He also devised several types of high frequency galvanometers with photographic arrangement for recording. An interesting problem he investigated was the determination of the half life for spontaneous fission of U^{235}.

He used two independent methods for the purpose of counting (i) the number of fission particles emitted per unit area per unit time from a thin coating of uranium

oxide on the inner side of an ionization counter and (ii) the number of neutrons emitted from a large mass of uranium oxide surrounding a large BF_3 proportional counter. It was taken that for each fission 2-3 neutrons were emitted. The two methods gave a mean life for spontaneous fission of the order $1{\cdot}3 \times 10^{16}$ years in general agreement with other determinations, against Bohr and Wheeler's theoretical estimate of 10^{22} years.

A number of determinations has been made on the slow-neutron absorption cross-sections in different materials like uranium oxide and in some other elements and of their compounds. The neutron source used up till now was a 100 mc. radium-beryllium one, and the detector was a silver plate the β-ray activity of which following neutron absorption was measured by a special β-ray G.M. counter. Such an arrangement has drawbacks with respect to sensitivity and lack of precise definition of the detector volume.

Similarly a large number of measurements has been made on the absorption cross-section of γ-rays, from Ra and Co^{60} sources, in different elements (with atomic number varying from 12 to 82) and of their compounds. Investigations have also been undertaken to verify the claims made by Clay and others, of the occurrence of anomalous absorption cross-section at larger absorber thickness (15 to 30 cm.) of lead. Explanations of the observed anomalous effect offered are that it is due (i) to the effect of degenerate scattered secondaries or (ii) to the production of a new kind of penetrating secondary radiation.

G.M. counters were employed for γ-ray detection also. Under large absorber thicknesses the counts due to the primary γ-rays become of the same order of magnitude as that due to background radiation.

For more accurate absorption measurements of neutrons and gamma-rays in different substances, the technique of employing scintillation phosphors both solid (crystalline and amorphous) as well as liquid, together with photomultiplier tubes has been developed.

The advantages of the new technique are: (i) the size of the detector can be reduced in volume, and geometry can be much better defined: (ii) by using coincidence counting and method of energy pulse discrimination, it is possible to eliminate background effects, due to cosmic radiation, secondary scattering effect, etc. At the same time strong pure sources of γ-rays (like Co^{60} and Sb^{124}) uncontaminated with neutron are being employed.

(*f*) *Neutron Generator.*—After over 10 years of effort, it has been possible to construct in the Institute a medium voltage neutron generator. The experimental arrangement used has undergone continuous modification in line with the improvements of techniques effected in western countries. The method consists in accelerating a beam of deuterons through a medium voltage, which strikes a target of zirconium foil on which tritium gas is absorbed, when monoenergic neutrons are produced according to the following reaction

$$D_1^2 + T_1^3 \rightarrow He_2^4 + n_0^1 + 17{\cdot}3 \text{ meV}$$

A deuteron beam is produced by passing a stream of deuterium gas at low pressure through a glass discharge tube, round which a high frequency (20 mc./sec.) current flows through a solenoid. With a current of $1\mu A$ and an acceleration voltage of 52 kV a neutron beam of intensity equivalent to that produced by 770 mc. of radium-beryllium has been obtained. With the existing apparatus it will not be

difficult to increase the intensity of the emitted neutron beam 50 times. It is proposed to utilize the neutron beam for physical as well as biological investigations.

A Cockroft-Walton voltage multiplication unit, using a high frequency primary voltage of 10 kV at 100 kc./sec., with selenium rectifiers and small condensers is being used to generate a d.c. voltage of about 240 kV.

VI. Chemistry

In 1939, the Department of Chemistry was in charge of Professor N. C. Nag, the then Assistant Director. Although Nag retired in 1939, he maintained connection with the Bose Institute for another five years as honorary Assistant Director. Investigations on plant biochemistry and plant products were in charge of Dr. H. K. Banerjee, till he left the Institute in 1943. Dr. Basudev Banerjee joined the Institute as a Research Fellow in 1943 and continued to work till his death in 1953. Dr. J. K. Chowdhury was appointed Head of the Department of Chemistry in 1947. After his retirement in 1954, Dr. P. K. Bose succeeded him.

The investigations carried out in the department can be divided into certain chronological groups:

(i) N. C. Nag's pioneering studies with rats on the comparative nutritional values of oils extracted from *mutur* (*Pisum sativum*) and *chola* (*Cicer arietinum*) showed that the oil from *mutur* contained an antifertility factor. This work has been followed by S. Sanyal, who has isolated the anti-fertility factor, and carried out a large number of trials on animals, as well as human subjects.

(ii) H. K. Banerjee initiated certain investigations on the proteolytic enzymes present in the leaves of *Clerodendron infortunatum*. Later on with B. K. Kar, he investigated the biochemical changes involved in the growth, ripening, and senescence, in mango and guava.

(iii) During 1941-42, it had been established in the Plant Physiology Department, that the mechanical pulsation of the leaflets in *D. gyrans* was due to the photosynthesis of carbohydrates in the leaflets and their subsequent oxidative breakdown, which supplied the energy for mechanical work. Certain parallelism was noticed between the biochemical processes involved in the rhythmic pulsation of isolated animal hearts, and that of an isolated leaflet of *D. gyrans*.

During the war years, it was not possible to import essential chemicals like ATP, adenylic acid, nucleic acid, glucose-1-phosphate, etc. necessary for following this line of comparative biochemical investigation. Special efforts were therefore made to prepare glucose-1-phosphate by treating soluble starch with phosphorylase extracted from potato. Different methods of preparation were tried, but the purity of the final product, as tested on *Desmodium* leaflets, was not satisfactory. Some investigations were carried out to isolate and identify adenylic acid and nucleic acid from the pulvini of *M. pudica* and *D. gyrans*, by comparison with similar compounds prepared from yeast. These investigations were not fruitful, due to lack of essential technical aids necessary for isolation and purification of such large molecules of biological importance from plant materials. With the completion of the low temperature laboratory equipped for enzymatic studies, these investigations will be taken up again.

The other enzymes which were isolated and studied were amylase, phosphorylase, and phosphatase, which are responsible for conversion of starch and glycogen

found in the core of date palms to soluble sugars present in the sap exuded from incisions.

(iv) As has been mentioned under Plant Physiology, J. C. Bose had, by employing different staining techniques, established the presence of an active substance, having unsaturated carbon bonds in the contractile pulvini of many motile plants. This substance was neither a fat nor a lipoid. Recent investigations have made it plausible, that this stainable substance is identical with vacuoles containing tannin sacs. These are present in the active contractile cells in the pulvini of mimosa and similar plants.

The investigations carried out by Kuhn and Moewus with the chemical substances found in the alga *Chlamydomonas eugamatos* attracted a great deal of attention. They had reported that certain carotene compounds perform important physiological rôles in these algae, e.g. crocin induces motility and *cis-* and *trans-*methyl esters of crocetin have sex-determining properties. It was thought that J. C. Bose's active substance might be a carotenoid.

The first step in the investigation, which began in 1943, was the preparation of pure crystals of crocin, crocetin and other carotenoid compounds from saffron. The next step was the isolation of similar compounds from the pulvinus of *M. pudica*. Actually crocetin crystals were obtained. Further *in situ* micro-chemical tests were performed on sections of the pulvini of *M. pudica* and of other motile plants, to establish the presence of these carotenoid compounds. Molisch's reagent II, containing *p*-dimethylaminobenzaldehyde dissolved in sulphuric acid, was employed for this purpôse. It was concluded that crocin was present in fair concentration in the cells of pulvini of several motile plants. It was later proved that crocin did not possess the primary characteristic of the irritability substance present in *Mimosa*. An account of this last named substance is given below:

The existence of the irritability substance was demonstrated by the discovery of Ricca in 1917, that a hot water extract of macerated *Mimosa* stem, when introduced into the cut stem of a *Mimosa pudica* unit, induced closure of leaflets, followed by subsequent recovery. Obviously a chemical mediator, the rôle of which is analogous to that of acetylcholine in the chemical transmission of excitation between motor nerve ending and effector muscle, exists in *M. pudica*. A number of plant physiologists in Germany, namely Haberlandt, Umrath, Fittig, and Hesse have tried to isolate this irritability substance from *Mimosa*, but due to the high oxidizability of the purified product, the substance has not yet been obtained in a pure form nor has its constitution been determined. Efforts to purify this substance in the chemical laboratory of the Bose Institute was commenced in 1946-47 by Basudev Banerjee, but a final solution of the problem has yet to be reached. Basudev Banerjee spent the year 1950-51, working on this problem with Kuhn and Moewus in Heidelberg, and with Hesse in Freiburg. In course of these investigations, the techniques of columnar and paper chromatography were first employed in the Institute. Subsequently these techniques have found extensive applications in the Institute, which will be described later. One difficulty in the isolation of this so-called irritability substance is that there is no method for estimating its activity, except biological tests with cut *Mimosa* pulvinus petiole unit, the sensitiveness of which fluctuates with daylight, season and other factors. A method developed by Bautner, of determining the activity of alkaloids as well as of the chemical mediator acetyl choline in a concentration cell with an oil-layer intervening between

the two electrolytes, is being tried. The apparatus may provide an objective method of assaying the activity of the irritability substance at different stages of its purification.

(v) In 1947 the newly appointed Head of the Department, Dr. J. K. Chowdhury brought along with him two C.S.I.R. schemes: The first one was the study of the sulphur contents of different samples of Assam coal, and their economic methods of desulphurization and the feasibility of utilizing the sulphur eliminated during the desulphurization process.

The next [illegible] investigations related to the use of a cheap substitute, the bleaching [illegible] the more costly sodium chlorite for bleaching of jute fibre, and then to increase the wet strength of such bleached fibre by impregnation with synthetic resins. Cationic melamine and Ciba 286 were found to be both effective and reasonably cheap. The resulting wet strength is about 60 per cent of the unbleached yarns.

The mode of disintegration of the cementing substances in jute fibre by retting micro-organisms has been studied. Pectin-like substances were extracted and purified and their breakdown, under the action of pectinase obtained from several retting bacteria and fungi, was compared with that of low methoxy citrus pectin. The end-products were in both cases galacturonic acid. The enzyme systems isolated from various ret-causing fungi were subjected to paper chromatography. It has not yet been possible to separate the components of the enzyme system.

It was reported under Cytogenetics Section that a new mutant called T.M. has been evolved out of *C. olitorius*, variety R26. A comparative study of the chemical constitution of the fibres from R26 and T.M. revealed slight but not very marked differences.

Synthesis of Weedicides.—2: 4-Dichlorophenoxy acetic acid (2, 4-D) was synthesized by two different methods. A new herbicide 2-methyl-4-chloro-5-*iso*-propyl phenoxy acetic acid was also prepared. Its toxicity was compared with that of 2, 4-D by spraying on water hyacinth leaves. The latter was found to be less toxic. The cost of local manufacture of these weedicides will remain high, unless the basic chemicals can be manufactured locally and cheaply.

Chromatography.—During the past four years extensive studies have been made on the technique as well as the applications of chromatography. Investigations have been conducted on the respective rôles of the paper, the solvent and the solute in the development of the chromatographic patterns. The respective merits as well as the drawbacks of the strip and of the circular methods of chromatography have been studied.

Paper ionophoresis method has been developed, and several applications of this technique have been made. A Tiselius electrophoresis apparatus has been constructed in the workshop and will soon be in use.

The work carried out in this section have been mainly in collaboration with the plant physiology, biochemistry, and microbiology sections. An account is given below of some of the investigations which have been carried out in this section.

Mapping of amino acids present in the leaves *M. pudica* and in the roots and nodules of leguminous plants.

Analysis of free sugars and amino acids present in coconut milk.

Breakdown products of pectin obtained from different sources by fungal pectinases and by mineral acids.

Identification of organic acids present in plant tissues which take part in the Krebs cycle.

Breakdown products of nucleic acid.

Ionophoretic method of analyzing the constituents of alkaloids present in cinchona, opium and *Strychnos.*

Studies on metabolism in plants, using radioactive tracers P^{32}, C^{14} and S^{35}, including—

(*a*) phosphorus metabolism in *mung* and *chola* seedlings.

(*b*) intermediate products during photosynthesis in tobacco and *Canna* leaves and in *Chlorella* and other algae.

Ionophoresis method has been applied in the separation of uranium and thorium from rare earths present in monazite sand and in the analysis of inorganic cations and anions.

In addition colorometric methods have been utilized for estimation of the minimum amount of uranium detectable in a given sample. The uranium and thorium contents of monazite and pitchblende have been estimated. Pu^{239} present in pitchblende in micro-concentration has been separated and precipitated with lanthanum fluoride. Black sand thrown up on the Puri beach has been analyzed and found to contain silica, ilmenite, bauxite and monazite.

VII. Microbiology

This Department was started in 1942 with the following honorary workers: Dr. H. K. Baruah, Mrs. Parukutty Baruah, Dr. Nepal Chandra De and Sri (now Dr.) P. N. Nandi. For a few years both Dr. De and Dr. Baruah officiated as research fellows in microbiology. At present Dr. P. N. Nandi is Head of the Department. Since its commencement, this Department has been interested in the study of certain important problems some of which are mentioned below:

1. Microbial disease of tropical fruits.
2. Microbial retting of jute.
3. Antibiotic-producing soil micro-organisms.
4. Bacterial and fungal antagonism amongst soil micro-organisms.
5. Purification and semi-large scale production of antibiotic substances.
6. Nitrogen fixing bacteria; soil bacterization as an aid to growing of leguminous plants.

Study of the diseases of tropical fruits and vegetables was undertaken from the following points of view: (*a*) nature of relation between parasite and its specific host, (*b*) nature of infection, (*c*) mechanism of rotting, (*d*) factors influencing the susceptibility of fruits, and (*e*) control of wastage. Amongst the fruits studied were apple, pineapple, mango, etc. This investigation was not pursued for long but its importance lay in the discovery by Baruah of a fungus (*Thielaviopsis paradoxia*) in rotting pineapples, which was used later for the controlled retting of jute and other bast fibres like ramie, flax, etc.

Microbial retting of jute.—As mentioned above, the fungus *T. paradoxia* had powerful rotting activity on pineapple. This fungus when cultured on suitable substrate (like wheat bran) was found to secrete an enzyme which could quickly ret jute fibres. The procedure was to introduce the activated substrate in a water-filled metal container, in which jute sticks had been steeped. Retting was complete

within 24 hours while under natural conditions it takes 3-4 weeks. The isolated enzyme system was found to contain a pectinase. The breakdown product of the pectin cementing the fibres was found to be galacturonic acid and a number of other organic substance like acetone, alcohols, etc. Later some retting bacteria were isolated. A retting substance named *Hiparol* was made from the fungus-activated substrate, which together with a preparation of retting bacteria was successfully employed for semi-large scale application in a few mills under the Indian Jute Mills Association, for processing and softening of jute root cuttings. Favourable reports were received of *Hiparol* replacing several of the intermediate processes necessary for preparing jute root cuttings for manufacturing purposes. The work was discontinued after Dr. Baruah's departure in 1946.

This line of investigation was resumed in 1951 by R. K. Bose. After a prolonged search for suitable retting bacteria and fungi, two strains belonging to the fungus *Aspergillus niger* were found to be most effective. One of these was isolated from rotting tamarind, and the other from retted jute stem. With these the retting of jute could be completed in 24 hours. The first fungus was comparatively more active. For semi-pilot plant experiments, the fungus was cultured on different substrates. The retting activity of the cultured substrate was highest when the fungus had no other supply of carbohydrate than jute stems. The fungus grew vigorously in presence of sugar, but it lost its retting capacity. Next to jute stem wheat bran was found suitable; on the other hand rice bran was not suited for pectinase secretion by the fungus.

This is probably an example of enzymatic adaptation by micro-organisms; the latter react to different substrates by altering their enzymatic secretion adjusted to the nature of the substrate offered. This important problem of enzymatic adaptation is being further followed up.

Bose employed the cultured substrates for stack-retting of jute. In West Bengal and other jute-growing areas of the Indian Union, large volume of slow moving water, as found in East Bengal, is not available for retting. In the process used by Bose, stacked jute sticks, kept moistened, were strewn with the cultured substrate. The sticks were retted in 3-4 days. It will be necessary to repeat the experiments on a large scale during the next jute season to test the practicability and ascertain the economics of the process.

Antibiotic-producing soil micro-organisms.—Investigations were commenced in 1943 on the isolation of soil micro-organisms like *Penicillium* which produced the then widely utilized antibiotic *penicillin*. The work was started by Baruah, and was later followed up by N. C. De. Of the ten strains isolated, two were identified as *P. notatum* and *P. chrysogenum*. Starting with their culture in a modified Czapek-Dox medium, efforts were directed to the finding of the cheapest substrates and for simplifying the procedure for the maximum rate of yield of penicillin. The test organism used was *Staph. aureus*. The liquid extract containing the antibiotic substance was purified and concentrated; it found some useful application for treatment of sores and other external sites of infections. In 1946, some attempt was made by N. C. De to culture streptomycin-producing actinomycetes and to extract and purify the antibiotic substance. This period of work ended in 1947, with the departure of N. C. De.

In 1948, after the return of Dr. P. N. Nandi from his study leave in U.K., the work of the department was again renewed. An extended survey was made of soils

collected from different localities of West Bengal and other adjoining states, for the discovery of different types of micro-organisms, and testing their ability to secrete both antibacterial as well as antifungal substances. Of 540 isolated fungi, 139 were capable of producing antibiotic substances. They belonged mostly to the species of *Penicillium* and *Aspergillus*, and a few to *Fungi Imperfecti*. 206 species of actinomycetes were also isolated, of which 16 possessed antibacterial properties, both against gram-positive and gram-negative bacteria.

In 1950, two species of *Streptomyces* were selected for their antibiotic action on gram-negative organisms. One of them was found to be highly fungistatic.

Extracts of antibiotic substances from these organisms were tested on the following test organisms, *Staph. aureus*, *E. coli*, *Eb. typhosa*, *V. cholerae* and *K. pneumoniae*.

These actinomycetes were found to possess a wide range of antibiotic spectrum. In 1952, 20 strains belonging to *Streptomyces* were tested for their antifungal action on plant pathogens, which included *Helminthosporium oryzae*, *Helminthosporium* sp., *Curvularia* sp., *Verticillium* sp., *Alternaria solani*, *Cephalasphorium saccharum*, and *Fusarium* sp. Twelve were found to be completely negative, while the rest were active against some of the fungal strains. *Fusarium* was found to be the most resistant. The tentative conclusion has been reached that the *Streptomyces* spp. may play an important rôle in the control of plant pathogens in soil.

Extracts from culture of *B. subtilis* were found to possess not only antibacterial but also antifungal properties. The antifungal spectrum is large. The active substance was found to be a polypeptide. Its amino acid composition has been found to be different from that of other known fungistatic products of *B. subtilis*, like bacillomycin, mycosubtilin and fungistatin.

Studies were undertaken on the effect of antibiotic substances on the inhibition of nitrogen-fixing bacteria. The effect of pure antibiotic substances like *terramycin*, *streptomycin* and *penicillin*, on the growth of nitrogen-fixing bacteria like *Azotobacter*, and *Rhizobium* sp. has been studied. Their relative toxicity and the period of their effectiveness in the soil were also ascertained. Two actinomycetes strains *S. griseus* (streptomycin) and *S. venezualae* were cultured in soil, to find out if they produced antibiotic substances under such condition. Only one strain of *S. venezualae* was found to produce some antibiotic substance presumably chloromycetin while the other failed to produce any.

In 1953-54 the Institute received a grant from the C.S.I.R. for the production on a pilot-plant scale of an antibiotic substance isolated from a strain on *Streptomyces* sp. which was found to possess remarkable antibiotic properties against gram-positive, gram-negative and acid-fast bacteria. It was active against *E. coli*, *E. coli* R. (resistant to *streptomycin*), *B. cereus* var. *mycocides*, *B. subtilis*, *V. cholerae*, *A. aerogenes*, *Eb. typhosa*, *P. vulgaris*, *S. aureus*, *C. diptheriae*, *P. pyocyaneus*, *A. niger*, *Pythium* sp. The purified active principle was compared with other similar substances by the method of paper chromatography which indicated that it was different in nature from streptomycin and neomycin sulphate. Toxicity tests carried out so far against white Swiss mice revealed that intramuscular dosages of 125 dilution units were tolerated. From a study of some of the microbiological and chemical properties it appeared that the substance might belong to neomycin complex. To test the homogeneity of the substance as also for further purification of the product which still contains considerable amount of residual matter, it is

intended to pass it through the counter-current distribution apparatus which has been set up in the laboratory. A semi-large scale fermentor unit is being assembled.

VIII. Plant Disease

During 1942-43, the rice crop, both in fields and in storage, had suffered extensive damage due to infection with *Helminthosporium oryzae*, with which is often associated *Fusarium* sp. At that time Baruah had investigated the conditions which favoured the infection of rice plant by these fungi. The fungi could be isolated from various grasses and from samples of soil. The degree of resistance to infection in different rice plants was found to depend on its variety, on the vigour of the plant, and the water content of the soil. The production of toxic substances by the fungus during growth, and the nature of the breakdown of the various constituents of the cell wall were investigated. During 1952, Nandi, as reported under Microbiology, investigated the possibility of controlling such plant pathogens by the antifungal activity of some strains of *Streptomyces* sp. Preliminary investigations have led to the tentative conclusion that *Streptomyces* spp. may play an important rôle in the control of plant pathogens in soil.

Diseases of potato.—A. Ganguly, during his period of tenure of an I.C.I. Research Fellowship (1951–54), developed the Mayapuri Research Station, Darjeeling, as a centre for investigations of potato diseases of bacterial, fungal and virus origins. He discovered among the potatoes collected from the Government Potato Seed Farm at Rungbull, two new types of potato disease, not previously known to occur in this country. One was the discovery of the fungal disease known as Potato Wart in a variety known as *Furore* imported from Denmark. Another bacterial disease, due to the presence of a not-yet-identified rod-shaped gram-negative bacterium which produces black rings, was discovered in some varieties of potato. It is probably identical with the black leg or bacterial wilt of potato.

Virus disease of potato.—A. Ganguly had also made a survey of the different virus strains present in several commercial varieties of Indian potato, as well as the immunity of the latter against other virus strains. A promising line of investigation was started to evolve new strains of commercial potatoes by hybridization of the latter with different virus resistant wild potatoes collected from South America. and other resistant varieties evolved in different countries of the West. This investigation had to be discontinued in 1954 due to the departure of the Research Fellow. It will be resumed when funds are forthcoming from the local State Government.

IX. Zoology

A large number of isolated observations has been recorded on bat-eating spiders of Bengal, on the migration habits of *Hibiscus* caterpillars, on spiders which mimic tree ants and so on.

One of the important piece of investigations carried out in this department was a detailed study of the food habits, mode of propagatiom and the polymorphic forms of the aggressive red ants *Oecophylla smaragdina*, Fabr. The different castes in which they occur are males, queens and workers. By keeping the ants in artificial nests made of transparent cellophane paper, their food and breeding habits could be studied. From the results of investigations it appears (i) that sexual union between males and queens gives rise to workers, which are atrophied females and

that (ii) the males are produced from unfertilized eggs of queens. Further some of the workers themselves can also reproduce (asexually) and give birth to workers only. Queens are produced from worker larvae when given special kind of food collected by nursing workers, namely nectarine secretions from flower buds, aphids, mealy bugs, etc. It has not been possible to find out the special constituents of the nectarine, which change workers into queens. It is a kind of gigantism produced by the special food and is similar to the effect of royal jelly in the case of the honey bee. There is a great deal of similarity with the polymorphic forms in honey bees which belong to the same *Hymenoptera* class. Cytological investigations have shown that the drones have 16 chromosomes; in the diploid stage the queen has 32 chromosomes and so on. Unfortunately due to the difficulty of the technique, it has not yet been possible to carry on similar cytological investigations on the red ants.

It had been reported recently that addition of vitamin B_{12} or some antibiotic substance to the feed of fowls and pigs, accelerated their growth. After addition of vitamins B_1, E and some of the hormones in the feed stuff of ant larvae had failed to induce gigantism, the effect of some of the antibiotics (like penicillin, streptomycin) was tried. It resulted, however, in the worker progeny being further reduced in size.

Simply out of curiosity the effect of keeping tadpoles for a short period in a very dilute solution of penicillin was observed. The surprising discovery was made that the metamorphosis of tadpoles, which normally occurs between fourth and fifth weeks after hatching, could be retarded by more than one year in some cases. Further treatment of these retarded tadpoles with a dilute solution of vitamin B_{12} induced metamorphosis in them within a week. This effect has been observed with tadpoles belonging to the *Rana tigrina* as well as *Bufo melanostictus* species.

X. Geology

Work in this section of the Institute is going on since the appointment of Sri A. K. Ghosh as Registrar in 1948 with grants-in-aid received from the Burmah Oil Company. He is assisted by Sri A. Bose and Sri R. Mazumdar. A good deal of microfossil investigations has been done with the object (1) of finding out the geological age of the sedimentary rocks and (2) of tracing the phylogenetical history of vascular plants. Up till now, rock specimens from the Cambrians of the Panjab Salt Range (Pakistan), Kashmir (India) and the U.S.A., Pre-Cambrian and Cambrians of the Vindhyans, Pre-Cambrians of the Dharwars and the Cuddapah system, Cambrians or Post-Cambrians of the Mandi, Permians and Triassics of the Panjab Salt Range have been analyzed and studied. From the results obtained so far it is evident (*a*) that the vascular plants have their early origin in the Cambrians possibly also in the Pre-Cambrians and (*b*) that the vascular plants have evolved in polyphyletic lines.

Besides microfossil investigations, attention has also been given to macrofossils. Several petrified woods from Maurbhanj (Orissa) have been identified.

XI. Anthropology

With the coming of Dr. D. M. Bose in 1938 as Director of the Institute, the anthropological researches, which had so far been confined to the ethnological

studies of the aboriginal peoples only, were reoriented to include the study of human heredity. Dr. S. S. Sarkar, Research Fellow in Anthropology, was awarded the Humboldt Stiftung of the Berlin University the same year and returned in 1939 after one year's training under Prof. Eugen Fischer at the Kaiser Wilhelm Institute for Anthropology, Berlin. He specialized on methods of researches on twins. The work carried out by him in Berlin was published in the *Transactions of the National Institute of Sciences of India* (Vol. 11, 1944). After his return, researches on twins were systematically carried out at the Institute. An all-India survey to determine the frequency of twin and other multiple births, was carried out. Blood grouping investigations and an elaborate survey of the peoples of Bengal and Bihar were also carried out.

I. SOME EXPERIMENTS ON PARAMAGNETIC SALTS

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Introduction and Experimental Details

The magnetic anisotropy of a single crystal of magnetic material can be easily deduced from the couple exerted on it by a uniform magnetic field. K. S. Krishnan and his colleagues at the Indian Association for the Cultivation of Science developed various ingenious methods for measuring such couples, and have studied the anisotropy of a great variety of materials at temperatures above about 80° K. For paramagnetic salts such studies have yielded much valuable information about the perturbing influence of the strong crystalline electric fields and the spin orbit coupling which are primarily responsible for the magnetic anisotropy of such salts. Comparison with the detailed theory developed particularly by Van Vleck and his school has not only led to quantitative information about the behaviour of paramagnetic ions in a crystalline environment, but has stimulated development and refinement of the theory. Relatively little attention has, however, been devoted to the much stronger magnetic anisotropy of paramagnetic crystals at lower temperatures and it seemed therefore worth while to make some measurements in the range of liquid helium temperatures, with the following aims in view:

(*a*) to see how far the temperature variation of anisotropy in this range of temperatures agrees with that already studied at higher temperatures;

(*b*) to look for saturation effects in the anisotropy at higher fields;

(*c*) to look for anisotropy in the saturation region in crystals which are normally isotropic (e.g. cubic crystals); and

(*d*) to study the couple arising from the shape of the specimen. This couple, as will be explained later, is proportional to the square of the magnetization, and at higher temperatures is merely an annoying small effect which has to be eliminated in measurements of crystalline anisotropy. At low temperatures it can, however, become very large and, as we shall see, can yield useful information about the magnetic properties.

Since only a few weeks were available for the work, the measurements were necessarily of an exploratory character and there had to be some sacrifice of experimental accuracy for the sake of speed. The experimental method was to suspend the crystal from a short torsion wire and to observe the deflections of the image of an illuminated slit reflected on to a distant scale from a small mirror attached to the suspension. This method lends itself particularly to the study of non-linear magnetization-field dependence since by making the torsion wire sufficiently stiff the angular motion of the crystal can be restricted to small values (of order one or two degrees) and the couple can be measured at any desired orientation, without the complication of instability effects. The apparatus

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used was developed for studies of the de Haas-van Alphen effect and is similar to one already described (Shoenberg, 1939, 1952); it was set up in the large electromagnet of the N.P.L. which gives fields up to 33 KG with 1″ pole faces for a gap of 29 mm. It was soon found, however, that it was quite impracticable to use the 1″ pole faces for paramagnetic work since the field was not sufficiently homogeneous, leading both to spurious couples and to sideways instability which made measurements impossible when, as at low temperatures, the magnetic moment became too high. This difficulty was eliminated by changing to pole pieces with 5¾″ faces, which gave only slightly smaller fields (up to about 28 KG for a gap of 32 mm.), but much greater homogeneity.

The crystals studied were potassium chrome alum ($CrK(SO_4)_2 . 12H_2O)_2$, nickel sulphate hexahydrate ($NiSO_4 . 6H_2O$) and copper potassium sulphate ($Cu(KSO_4)_2 . 6H_2O$). The first of these being cubic, is particularly suitable for (*c*) and (*d*) above, and the effects of (*c*) and (*d*) could be studied simultaneously by suspending the crystal in the form of a vertical rectangular plate. The second is tetragonal, and the use of a rectangular plate with the tetragonal axis parallel to one edge of the plate and suspended with this edge vertical again enables (*c*) and (*d*) to be studied, since the crystal is normally isotropic in the plane normal to the tetragonal axis, while the use of a cylinder suspended with its axis vertical and with the tetragonal axis horizontal, eliminates the effect (*d*) and gives information on (*a*) and (*b*). The third is monoclinic and also gives information on (*a*) and (*b*); here again cylindrical specimens were prepared to eliminate (*d*), one with the monoclinic (*b*) axis vertical, and one with the (001) or (*ab*)-plane horizontal. The choice of nickel sulphate hexahydrate and copper potassium sulphate was partly governed by the consideration that they provide examples of two very different types of temperature dependency of anisotropy.*

FORMAL THEORY OF THE COUPLE ON AN ANISOTROPIC CRYSTAL IN SATURATION CONDITIONS

Before describing the experimental results we must first consider what can be predicted about the couple acting on a crystal in conditions where the magnetization I is no longer proportional to H. We shall first ignore shape effects (as is justified for a sphere or a cylinder with its axis perpendicular to the field), and consider the case where I can be usefully expanded in powers of H, i.e. the initial stage in the departure from linearity. The free energy F from which I is derived can then be expanded in even powers of H, and if the z-axis is vertical and perpendicular to H, F must have the form

$$F = \tfrac{1}{2}(k_{11}H_1^2+2k_{12}H_1H_2+k_{22}H_2^2)+\tfrac{1}{4}(aH_1^4+4bH_1^3H_2+2cH_1^2H_2^2+4dH_1H_2^3+eH_2^4) + \text{higher order terms} \quad .. \quad (1)$$

The couple acting on the crystal about the z-axis is most simply derived as $C = -\partial F/\partial\theta$, where θ is the angle between H and the x-axis. In terms of θ, we have

$$F = \tfrac{1}{2}H^2(k_{11}\cos^2\theta+2k_{12}\cos\theta\sin\theta+k_{22}\sin^2\theta)+\tfrac{1}{4}H^4(a\cos^4\theta+4b\cos^3\sin\theta + 2c\cos^2\theta\sin^2\theta+4d\sin^3\theta\cos\theta+e\sin^4\theta)+\text{etc.} \quad .. \quad (2)$$

and we find

$$C = \tfrac{1}{2}H^2\{(k_{11}-k_{22})\sin 2\theta-2k_{12}\cos 2\theta\}+\tfrac{1}{2}H^4\left(\frac{a-e}{2}\sin 2\theta-\frac{b+d}{2}\cos 2\theta + \frac{a+e-2c}{4}\sin 4\theta-\frac{b-d}{2}\cos 4\theta\right)+\text{etc.} \quad .. \quad (3)$$

* The measurements on these two salts were also carried out at liquid oxygen temperatures and agreed well with the data collected at Indian Association for the Cultivation of Science, thus serving as a check upon the accuracy of our present method.

This expression simplifies greatly if the crystal has some symmetry and if x and y are symmetry axes; we shall examine one or two special cases:

(*a*) *Tetragonal symmetry, x along the tetragonal axis, y along a binary axis.*

The symmetry requirements are that if H_1 is changed to $-H_1$ but H_2 unchanged, or if H_2 is changed to $-H_2$ but H_1 unchanged, F must remain unchanged. These requirements demand $k_{12} = 0$, and $b = d = 0$, so that (3) reduces to

$$C = \tfrac{1}{2}H^2 \sin 2\theta\left\{(k_{11}-k_{22})+\frac{a-e}{2}H^2+\frac{a+e-2c}{2}H^2 \cos 2\theta\right\} \quad .. \quad .. \quad (4)$$

it may be noted that the zeros of C are now 90° apart, which is not in general true for (3).

(*b*) *Either cubic symmetry, with x and y tetrad axes, or tetragonal symmetry with the tetragonal axis vertical and x and y binary axes.*

There is now the additional symmetry requirement that the x and y axes are equivalent, so that $k_{11} = k_{22}$ and $a = e$, and (3) becomes

$$C = \tfrac{1}{8} H^4(a-c) \sin 4\theta ; \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (5)$$

there is of course no couple unless non-linear terms occur in the field dependence of magnetization (i.e., unless 4th order or higher terms appear in the free energy).

The calculation of terms of higher order in H in equations (1) to (5) is straightforward though tedious, and we shall consider only the case (*b*) where the derivation is particularly simple. For this case, it is evident that all terms containing odd powers of H_1 or H_2 must vanish, and that the coefficients of terms which can be obtained from each other by interchange of the suffixes 1 and 2 must be equal. Thus (1) can be expressed as

$$F = \sum_{n=1} f_n(H^2, H_1{}^2-H_2{}^2) \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (6)$$

where f_n is a homogeneous function of order n, but symmetrical in H_1 and H_2, i.e. containing only *even* powers of $H_1{}^2-H_2{}^2$. Introducing the angle θ as before, this can be written as

$$F = \tfrac{1}{2} \sum_{n=1} H^{2n}(a_{0n} + \tfrac{1}{2} a_{2n} \cos^2 2\theta + \tfrac{1}{4} a_{4n} \cos^4 2\theta + \ldots .)$$

where it is understood that in a_{rn}, r must not exceed n. The couple then becomes

$$C = \sin 2\theta \sum_{n=2} H^{2n}(a_{2n} \cos 2\theta + a_{4n} \cos^3 2\theta + \ldots .),$$

and it is now a simple matter to write down the couple to any order in H; the first few terms are

$$C = \sin 2\theta(H^4\, a_{22} \cos 2\theta + H^6\, a_{23} \cos 2\theta + H^8\, (a_{24} \cos 2\theta + a_{44} \cos^3 2\theta) + \text{etc.}) \quad .. \quad (7)$$

The leading term agrees, of course, with (5) if we identify a_{22} with $\tfrac{1}{4}(a-c)$, and it should be noticed that the form of the angular variation of C differs from (5) only when we reach the H^8 term.

We must now consider the couple due to anisotropy of shape. We shall discuss only the simple case of an ellipsoidal specimen which has a principal plane horizontal and whose major and minor axes in this plane coincide with the x and y axes of the crystal. Moreover, we consider only the case (*b*) above, so that x and y are crystallographically

equivalent. Let the applied ('external') field be H_e and N_1 and N_2 the demagnetizing coefficients for the field respectively in the x and y directions; the field H in the material will then have components

$$H_1 = H_{e1} - N_1 I_1, \quad H_2 = H_{e2} - N_2 I_2, \quad \ldots \quad (8)$$

and the couple will be

$$C = I_2 H_{e1} - I_1 H_{e2} \quad \ldots \quad (9)$$

From (6) it follows by partial differentiation that we have

$$I_1 = H_1(\phi+\psi), \; I_2 = H_2(\phi-\psi) \quad \ldots \quad (10)$$

where $\phi = -2\partial F/\partial(H^2)$ and $\psi = -2\partial F/\partial(H_1^2 - H_2^2)$ and we may note that

$$\psi = \frac{1}{H^2 \sin 2\theta}\frac{\partial F}{\partial \theta} = -\frac{C_0}{2H_1H_2}, \quad \ldots \quad (11)$$

if we use C_0 to denote the couple given by (7). Substituting (8) and (10) into (9) we obtain

$$\begin{aligned} C &= (H_{e2} - N_2 I_2) H_{e1} (\phi-\psi) - (H_{e1} - N_1 I_1) H_{e2} (\phi+\psi) \\ &= -2H_{e1} H_{e2} \psi + H_{e1} H_{e2} \left(\frac{N_1 I_1^2}{H_1 H_{e1}} - \frac{N_2 I_2^2}{H_2 H_{e2}}\right) \quad \ldots \quad (12) \end{aligned}$$

It is now possible to approximate by ignoring the distinction between H and H_e in (12), and fortunately this is usually a good approximation since in practical conditions NI rarely exceeds 5% of H_e, (12) then becomes just

$$C = C_0 + \tfrac{1}{2} H_e^2 \sin 2\theta \left\{ N_1 \left(\frac{I_1}{H_{e1}}\right)^2 - N_2 \left(\frac{I_2}{H_{e2}}\right)^2 \right\} \quad \ldots \quad (13)$$

where in C_0 we substitute H_e for H, and θ is now understood to mean the angle between x and H_e. It can be seen that (13) is essentially the sum of two quite separate effects: the crystalline anisotropy effect already discussed and a couple due to the anisotropy of shape.

If as may happen in practice, the crystalline anisotropy is almost absent, or if $\theta = 45°$, (13) simplifies to

$$C = \tfrac{1}{2}(N_1 - N_2) I^2 \sin 2\theta \quad \ldots \quad (14)$$

and a better approximation (taking the difference of H and H_e into account) is given by adding a factor $\{1 + (N_1 + N_2) I/H_e\}$, though for the practical case of potassium chrome alum this factor is at most only 1·03 and drops to 1·015 at higher fields.

For paramagnetic crystals this couple due to shape becomes quite large at low temperatures and provides a simple method of studying the variation of I with H without the use of inhomogeneous fields. It has of course the drawback that determination of absolute values of I depends on a precise knowledge of N_1 and N_2, which is rarely available, but the scale of I can often be determined from other considerations such as knowledge of the saturation magnetization or the susceptibility in the linear region. The use of this method will be illustrated by our results on potassium chrome alum which turns out to be very nearly isotropic even in the saturation region where the formal considerations would permit anisotropy. Nickel sulphate hexahydrate in the plane normal to the tetragonal axis offers a pretty example of a case where strong crystalline anisotropy effects do occur, but by working at $\theta = 45°$, it is still possible to deduce the form of the I–H curve.

Finally we should mention that it is not difficult to generalize the theory to cover the case when the principal axes of shape do not coincide with the crystal axes. To the approximation in which the shape and crystalline effects may be considered separately, the result (13) is modified merely by a relative shift of the origin of θ in one of the two terms by the amount of the mutual inclination of the two sets of axes. This means that the zeros of C are no longer 90° apart, as they are in (13), and analysis of the results becomes more difficult. Such effects were obtained in an early experiment on nickel sulphate hexahydrate, but once the explanation was realized, care was taken to make the two pairs of axes coincide in all subsequent experiments, so that the results should be more easily amenable to analysis. Finally we should mention that although, strictly speaking, the theory assumes an ellipsoidal specimen, it probably applies fairly reliably to rectangular plates such as were used in our experiments, since the magnetization is never strong enough to cause much bending of the lines of force in the specimen.

Experimental Results

Potassium chrome alum

The specimen was prepared in the form of a rectangular plate about $3\frac{1}{2}$ mm. $\times 2\frac{1}{2}$ mm. $\times 1\frac{1}{2}$ mm., and originally weighed 0·0310 gm. Some difficulty was experienced due to dehydration under conditions of vacuum and low temperature, but it was possible to take measurements at the sacrifice of precise knowledge of the effective mass. After the experiment the crystalline part of the specimen had only about half the original mass, the rest having dehydrated into a powder. However, the reproducibility of check measurements suggested that either this dehydration did not much affect the magnetic behaviour—and this is quite plausible since hardly any crystalline anisotropy could be observed—or that the change of crystalline mass was not appreciable during the measurements. Fortunately it turns out that this uncertainty is not very important. Difficulty was experienced also in keeping the crystal stuck to the quartz rod of the suspension, as it often cracked, especially when too much Durofix cement was used for this purpose, and fell off leaving only a thin chip sticking to the rod. This was overcome by using only a trace of the cement and giving additional support to the crystal with strips of cigarette paper stuck directly to the quartz rod; this technique was used for the other crystals also.

The variation of couple with field was measured at 4·19° K. and at 1·70° K. for $\theta = 45°$, and the variation with θ at a fixed field (24·7 KG) was also measured at about 1·4° K. The latter was nearly a sin 2θ curve, though a slight sin 4θ term could just be detected * (roughly 4% of the sin 2θ term) showing that the first term of (13), arising from crystalline anisotropy, is almost negligible even in extreme conditions. The field variation curves were analyzed by comparing them with the appropriate Brillouin function which is

$$y = I/I_0 = \tfrac{4}{3} \coth 4x - \tfrac{1}{3}x \quad \ldots \quad (15)$$

where

$$x = \beta H/kT \quad \ldots \quad (16)$$

(I_0 is the saturation magnetization, given by $3N\beta$ per gm. ion, and β is the Bohr magneton). Assuming that (14) is valid, the square roots of the observed deflections should be proportional to I, and the constant of proportionality was chosen by fitting the ordinates as well as possible to the Brillouin curve.

* This particular rotation curve was not very accurately determined.

It was found, however, that the curves at different temperatures did not scale quite exactly in proportion to T as they should according to (16). In fact two small corrections are required, first for the demagnetizing effect, which makes the H of (16) slightly different from the applied field H_e:

$$H = H_e - NI, \quad \text{.. .. .. ..} \quad (17)$$

and second that Curie's law may not be exactly obeyed. The simplest way of dealing with the second possibility is to use the Weiss method, in which (16) is replaced by

$$x = \beta H_i / kT \quad \text{.. .. .. ..} \quad (18)$$

where

$$H_i = H - \lambda I \quad \text{.. .. .. ..} \quad (19)$$

(λ being an appropriately chosen constant). Although in fact the slight deviation from Curie's law is probably more a consequence of the crystalline electric field than of a magnetic interaction such as implied by (19), it is well known that the assumption (19) does produce a modification of Curie's law which is in fair agreement with the temperature variation of the low field susceptibility. Since the assumption works for the linear part of the magnetization curve, and it evidently becomes irrelevant at full saturation, where $y = 1$ regardless of what assumption is made, it must also provide a reasonably good approximation at intermediate fields. Combining (17) and (19) we have

$$H_e = H_i + (N + \lambda) I \quad \text{.. .. .. ..} \quad (20)$$

and it was found that the assumption $N+\lambda = 17$ gave the best fit at both 1·70° K. and 4·19° K. The procedure of fitting was first to calculate y as a function of x and then for each temperature to plot y as a function of the appropriate H_e as deduced from (18) and (20) (substituting $I = yI_0$ in (20)). The theoretical curves of I/I_0 against H_e for 1·70° K. and 4·19° K. are shown in fig. 1 and it can be seen that the experimental points (with

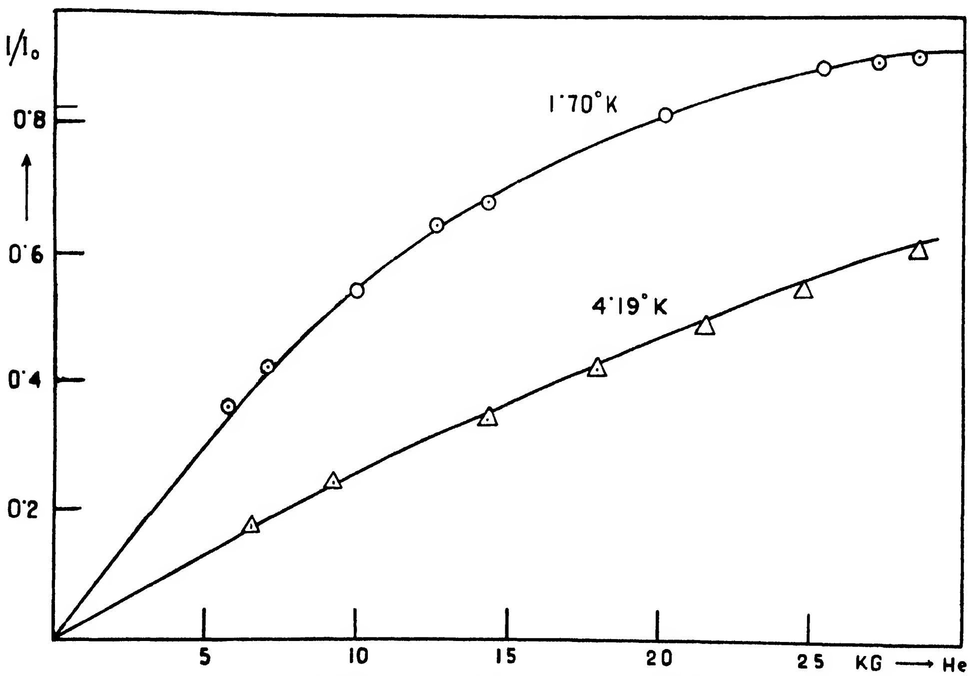

FIG. 1. Magnetization curves of potassium chrome alum.

the same scaling factor of ordinates for both temperatures, of course) lie very well on them.*

Although the estimate of $N+\lambda$ is very rough, it is worth deducing from it the Weiss temperature Δ in the Curie-Weiss law that the susceptibility varies as $1/(T+\Delta)$. The value of N can be guessed roughly as 6, so $\lambda \sim 11$ and we find Δ which is given by $\Delta = 5\rho N\beta^2\lambda/M^*k$ (ρ is the density and M^* the molecular weight), to be 0·08° K., which is of the right order of magnitude (de Klerk, Steenland and Gorter, 1949). It is also possible to work backwards from the scaling factor of the ordinates required to put the experimental points on the theoretical curves, and deduce the value of N_1-N_2. This comes out at about 1·6, which is not unreasonable in view of the fact that the thickness of the plate is not very much less than its width.†

Nickel sulphate hexahydrate

(*a*) *Tetragonal axis vertical.*—The specimen was a rectangular plate about 3 mm. × 3 mm. × 1 mm. and was ground so that the tetragonal axis was parallel to a vertical edge

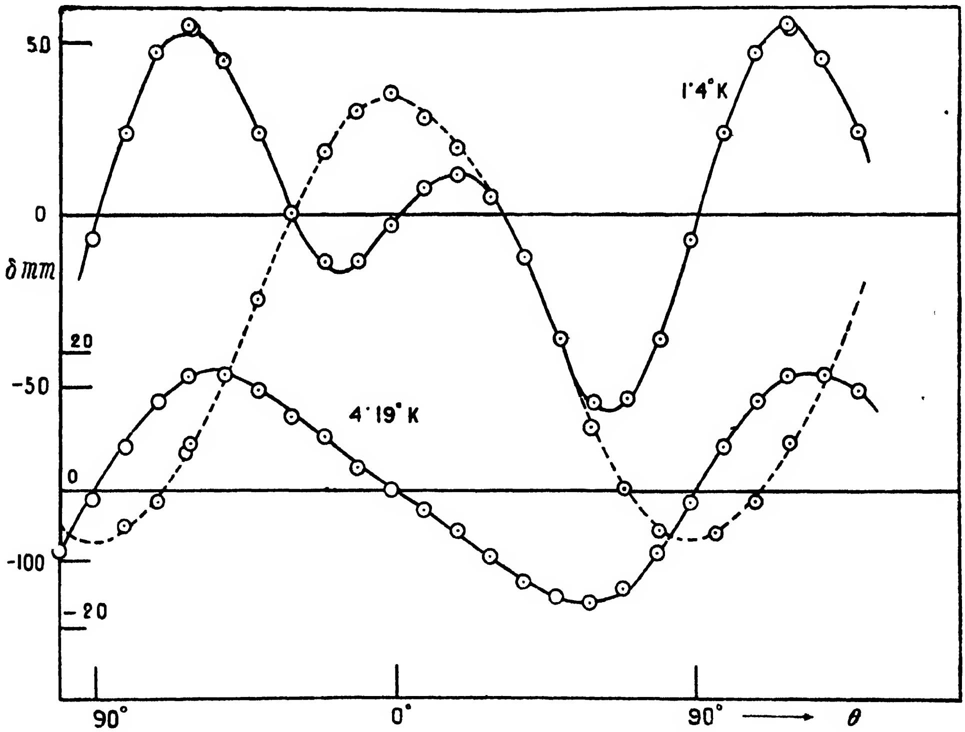

FIG. 2. Variation of δ, the deflection (proportional to the couple) with θ, the angle of rotation of the field from one of the zeros of δ, for nickel sulphate hexahydrate, at $H = 20$ KG. The broken curve is obtained from the 1·4° K. curve after division by sin 2θ.

* The agreement of the magnetization curve with the Brillouin function has been more critically examined by Henry (1952). He plots magnetization directly against H/T and finds slight discrepancies between the curves for different temperatures in the same sense as indicated by our results, but on the whole quite good agreement with the Brillouin function.

† This estimate assumes that the whole mass of the original crystal was effective; if a smaller mass is assumed, the estimate of N_1-N_2 is increased inversely as the square of the reduction factor.

and a binary axis to a horizontal edge. The rotation curves show marked $\sin 4\theta$ contributions (see fig. 2); they are most simply analyzed by dividing by $\sin 2\theta$ (the origin of θ being taken as one of the angles where C is zero). An example of this procedure is also illustrated in fig. 2 from which it can be deduced that at 1·37° K. and 20 KG the rotation curve has the form *

$$C = \sin 2\theta(30+33 \cos 2\theta)$$

(C in arbitrary units). Similar analysis of the other two curves which were measured gives (in the same units)

$$C = \sin 2\theta(14{\cdot}8+6{\cdot}5 \cos 2\theta)$$

for 4·19° K. and 20 KG

and

$$C = \sin 2\theta(5{\cdot}8+1{\cdot}2 \cos 2\theta)$$

for 4·19° K. and 11·5 KG.

If we interpret these figures in accordance with equation (13) we see that the crystalline anisotropy effect (which is of course absent at sufficiently low fields and higher temperatures) is quite marked even for 11·5 KG at 4·19° K. and become very large at 1·37° K. The coefficient of $\cos 2\theta$ should, for sufficiently low fields, vary as H^4 and should therefore be 9 times larger for 20 KG than for 11·5 KG; actually it is only about 5½ times larger, and though quite a large error is possible in the estimate at 11·5 KG, the discrepancy seems a little too large to be accounted for by experimental error. Possibly the influence of the terms in H^6 and H^8 in (7) is already appreciable, but it should be noticed that there is no evidence of any appreciable $\cos^3 2\theta$ contribution, such as might be expected if H^8 has to be considered, even in the much more extreme conditions at 1·37° K.

The curves of I against H_e for $\theta = 45°$ are shown in fig. 3; the absolute values of I were obtained in a manner to be explained below, but may be rather rough. Saturation effects are quite evident and it can be seen that something like 60% saturation is achieved at the lowest temperature. The magnetization curves at different temperatures can no longer be even approximately brought together by plotting against H/T, and there is no point in attempting a comparison with a Brillouin function since the mechanism of magnetization is evidently different from that in a nearly 'ideal' paramagnetic such as potassium chrome alum.

The reason for the much less marked dependence of the magnetization curve on temperature is presumably that the 3 spin states into which the ground level of the Ni^{++} ion is split (by the indirect effect of the crystalline field via the spin-orbit coupling) are separated by an energy difference $k\epsilon$ with ϵ of order 3° K. (for the Cr^{+++}ion the splitting is only of order 0·2° K). Thus at temperatures of the order of 1° K. only the lowest of these states is appreciably occupied and the magnetic properties become almost independent of temperature. Very roughly, we can picture the magnetization process in these conditions as orientation of the spin moments by the magnetic field in competition with the indirect effect of the crystalline field, which tries to keep the spin moments aligned in relation to the lattice (but in such a way as to produce no magnetization). This is in contrast to the usual process where the competition comes from the disorienting effect of temperature agitation, and we might expect that the fields required to produce saturation effects will be determined by $k\epsilon$ rather than by kT (as in the usual process). So far the

* The signs of the two terms in these expression are arbitrary, since no identification was made of the particular zero of C chosen as the origin of θ.

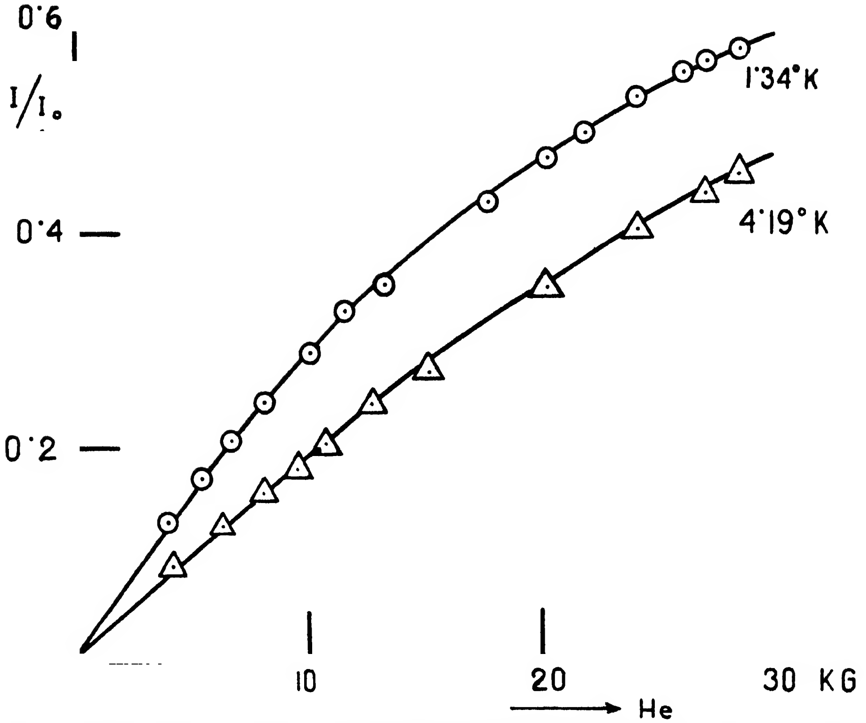

FIG. 3. Magnetization curves for nickel sulphate hexahydrate in the plane normal to the tetragonal axis.

quantitative theory of the magnetic behaviour of nickel salts (Schlapp and Penney, 1932) has not been developed to take account of saturation effects, nor as we shall see below have the expansions for the ordinary linear susceptibility been taken to high enough powers of $1/T$ to account completely for the results at very low temperatures. Such extensions of the theory, in conjunction with the experimental results, might give useful new quantitative information about the crystalline field. We may note also that it would be of interest to study potassium vanadium alum in which ϵ is probably several times larger than for nickel sulphate hexahydrate; thus the temperature dependence of the magnetization curve might be even less pronounced and the theory of the saturation effects might be simpler, if in consequence T could be treated as zero.

The temperature variation of the magnetization at 11·5 KG for $\theta = 45°$ is illustrated in fig. 4; since at this field saturation effects are not very marked (except at the lowest temperatures, where a slight correction can be made), the low field molar susceptibility χ_2 can be regarded as proportional to the magnetization. From the plot of $T^2\chi_2$ against T it follows that

$$\chi_2 = \frac{1{\cdot}18}{T} - \frac{1{\cdot}19}{T^2} + \frac{0{\cdot}2}{T^3} \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \; (21)$$

Here the constant of proportionality has been determined to make the $1/T$ term agree with the theoretical value discussed below; the significance of the other terms will also be discussed below.

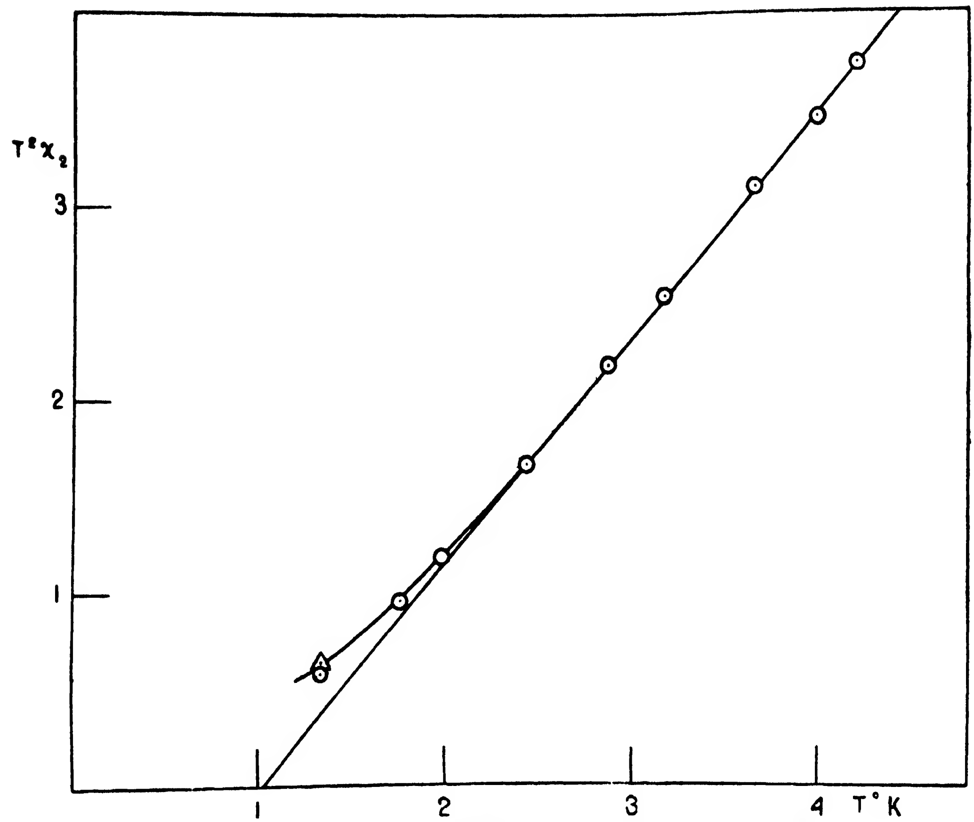

FIG. 4. Temperature variation of $T^2\chi_2$ for nickel sulphate hexahydrate.

(*b*) *Tetragonal axis horizontal.*—To avoid shape effects the crystal was ground into a cylinder and was suspended with the cylinder axis vertical; the mass was 0·013 gm. The temperature variation of $\chi_2 - \chi_1$ between 1·4° K. and 4·19° K. (measured at 6 KG) could be fitted quite well by the formula

$$\chi_2 - \chi_1 = \frac{1{\cdot}55 \times 10^{-2}}{T} + \frac{1{\cdot}88}{T^2} - \frac{1{\cdot}98}{T^3} \quad \cdot\cdot \quad \cdot\cdot \quad \cdot\cdot \quad (22)$$

apart from slight deviations at the lowest temperatures which suggest that a small positive $1/T^4$ term should perhaps also be included. In the fitting, a slight correction was applied to take account of the saturation effects mentioned below; this correction could only be roughly estimated and has possibly been exaggerated, so the coefficients of $1/T^2$ and $1/T^3$ may be too low by as much as 5% and 25% respectively. The term in $1/T$ was included so that the formula should agree with the data above 80° K. (Mitra, unpublished *). The coefficient of the term in $1/T^2$ agrees well with the value 1·87 found by Mitra, and since the $1/T^3$ term is negligibly small above 80° K., it can be concluded that the liquid helium results fit quite well with extrapolation from those at much higher temperatures.

* Mitra's absolute values of $\chi_2 - \chi_1$ are probably rather more accurate than those given by Krishnan, Mookherji and Bose (1939) though a slight discrepancy occurs between Mitra's data and the unpublished data by S. K. Dutta.

At higher fields, saturation effects are clearly noticeable; thus if C/H^2 is plotted against $1/H$ we get the curves of fig. 5,* and the rotation curves show appreciable sin 4θ components. There is, however, little point in discussing these results in any detail since the various coefficients in (7) have not yet been interpreted theoretically in more fundamental terms.

(c) *Discussion.*—Theoretical formulae for K_1, K_2 and K_3, the susceptibilities referred to the axes of the crystalline field have been given by Schlapp and Penney (1932), ignoring powers of $1/T$ beyond the square. If it is supposed that the crystalline field has tetragonal symmetry (Beevers and Lipson, 1932), these formulae are

$$\left.\begin{aligned} K_1 &= \frac{8N\beta^2}{3kT}\left\{1+(8\lambda-3kT)\alpha_1-\frac{4}{3}\frac{\lambda^2}{kT}(\alpha_1-\alpha_2)\right\} \\ K_2 = K_3 &= \frac{8N\beta^2}{3kT}\left\{1+(8\lambda-3kT)\alpha_2+\frac{2}{3}\frac{\lambda^2}{kT}(\alpha_1-\alpha_2)\right\} \end{aligned}\right\} \quad \ldots \quad \ldots (23)$$

Here λ is the spin-orbit coupling constant and α_1 and α_2 are parameters determining the crystalline field. The K's are related to the observed susceptibilities χ, by the relations

$$\left.\begin{aligned} \chi_1 &= K_1 \cos^2\phi+K_2 \sin^2\phi \\ \chi_2 &= K_1\, \tfrac{1}{2} \sin^2\phi+K_2(1-\tfrac{1}{2} \sin^2\phi) \end{aligned}\right\} \quad \ldots \quad \ldots (25)$$

where $\phi = 45{\cdot}7°$, is the angle between the tetragonal axes of the crystal as a whole and of the crystalline field 'seen' by one of the 4 ions in the unit cell. It follows that

$$(\chi_2-\chi_1) = \left(1-\frac{3}{2}\sin^2\phi\right)(\alpha_1-\alpha_2)\frac{8N\beta^2}{3kT}\left\{-(8\lambda-3kT)+\frac{2\lambda^2}{kT}\right\}$$

$$\chi_2 = \frac{8N\beta^2}{3kT}\left[1+(8\lambda-3kT)\left\{\tfrac{1}{2}\alpha_1 \sin^2\phi+\alpha_2\,(1-\tfrac{1}{2}\sin^2\phi)\right\} + \frac{2}{3}\frac{\lambda^2}{kT}(\alpha_1-\alpha_2)(1-\tfrac{3}{2}\sin^2\phi)\right] \quad (26)$$

and

$$\bar{\chi} = \frac{\chi_1+2\chi_2}{3} = \frac{8N\beta^2}{3kT}\left\{1+(8\lambda-3kT)\,\frac{(\alpha_1+2\alpha_2)}{3}\right\}$$

The value of λ may be immediately determined from the temperature variation of $\chi_2-\chi_1$ and comes out as $-480\,k$ (Krishnan, Mookherji and Bose, 1939); $\alpha_1+2\alpha_2$ can then be deduced from the absolute value of $\bar{\chi}$, and taking $\bar{\chi}$ at 300° K. to be $4{\cdot}04\times10^{-3}$ (S. K. Dutta, unpublished) we find $\alpha_1+2\alpha_2 = -95\times10^{10}$. The difference $\alpha_1-\alpha_2$ can be found from the absolute value of $\chi_2-\chi_1$, and using Mookherjee's (1946) value 84×10^{-6} at 300° K., we find $\alpha_1-\alpha_2 = 12{\cdot}6\times10^{10}$†. The second equation of (26) now enables us to find the constant of proportionality between magnetization and square root of deflection by comparing the coefficient of $1/T$ in the empirical expression for χ_2 with the theoretical value which, when numerical values of the α's, λ and ϕ are substituted becomes $1{\cdot}17\times8N\beta^2/3k$. It is in this way that the scale of figs. 3 and 4 and the absolute values in

* This form of plot has the advantage that it suggests the vanishing of C/H^2 for $1/H = 0$, which is of course plausible theoretically, though we have not considered the case of extreme saturation conditions in our discussion.

† Krishnan and Mookherji (1936) assumed in their calculation of $\alpha_1-\alpha_2$ that the K's could be equated to the corresponding observed χ's, and this assumption invalidates their determination, though it does not affect the determination of λ in the later paper (1939).

(21) have been fixed. We can now discuss the theoretical interpretation of the $1/T^2$ term in (21). Comparing the ratio of the coefficients of the $1/T^2$ and $1/T$ terms with the theoretical expression, we find

$$\frac{2}{3}\frac{\lambda^2}{1{\cdot}17k}\left(1-\frac{3}{2}\sin^2\phi\right)(\alpha_1-\alpha_2) = -1{\cdot}01$$

or

$$\alpha_1-\alpha_2 = -24\times 10^{10}$$

and we see at once that there is a contradiction here, since this makes $\alpha_1-\alpha_2$ negative, while the fact that $\chi_2 > \chi_1$ requires that $\alpha_1-\alpha_2$ should be positive. The origin of this contradiction is not clear, but it is possible that it is associated with the assumption that the crystalline field has tetragonal symmetry even at the helium temperatures.

Copper potassium sulphate

Two specimens were used, both in the form of cylinders with the axis of the cylinder suspended vertical. In one of them (mass 0·0143 gm.) the monoclinic *b*-axis was vertical, in the other (mass 0·0164 gm.) the (*ab*)-plane was horizontal.

The saturation effects were rather marked, as can be seen especially for the (*ab*)-plane horizontal at low temperatures (fig. 5). Correspondingly the rotation curves at 20·5 KG contained an appreciable sin 4θ component; for the *b*-axis vertical at 1·3° K. the curve can be described by

$$C = \sin 2\theta(20{\cdot}7+1{\cdot}0\cos 2\theta)$$

and for the (*ab*)-plane horizontal at 1·45° K. by

$$C = \sin 2\theta(27{\cdot}3+4{\cdot}7\cos 2\theta).$$

The units of C are arbitrary (and different in each expression) and the signs of the terms are arbitrary for the reason explained in the footnote on p. 8. It is interesting to note that the zeros of C are exactly 90° apart, i.e. that although the crystal is monoclinic there is no phase shift between the sin 2θ and the sin 4θ terms such as is permitted by the general formula (3). This indicates perhaps that the crystal symmetry is very nearly higher than monoclinic.

The saturation effects rather complicate the accurate interpretation of the data on the temperature variation of susceptibility. The torsion wire had been chosen rather stiff (in order to restrict the high field deflections) and consequently it was not possible to study the effect of temperature at a field low enough to keep the saturation effects small (this could of course be done with a thinner torsion wire). At the two end temperatures, however, the initial susceptibility could be estimated directly, though not very precisely, from the curves of fig. 5, and it was found that for the b axis vertical

$$(\Delta\chi) = \frac{8{\cdot}8\times 10^{-2}}{T} - \frac{1{\cdot}4\times 10^{-2}}{T^2}$$

and for the (*ab*)-plane horizontal

$$(\Delta\chi)' = \frac{2{\cdot}0\times 10^{-2}}{T} + \frac{0{\cdot}78\times 10^{-2}}{T^2},$$

assuming that only these two powers of $1/T$ are involved. As we have said, the accuracy is not high and it is possible that the results could be fitted by $1/T$ terms alone; the coefficients of $1/T$ would then be something like $8{\cdot}1\times 10^{-2}$ and $2{\cdot}2\times 10^{-2}$ if only the 4·19° K. points (where the saturation correction is small) were used.

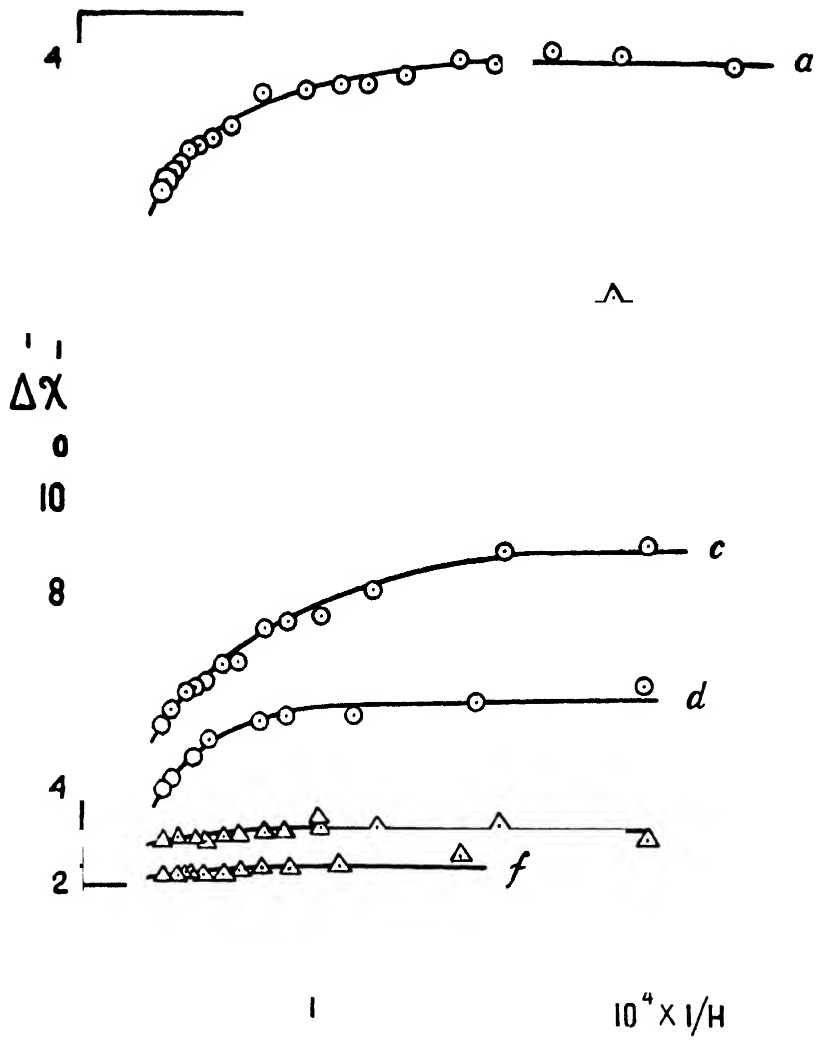

FIG. 5. Showing dependence of C/H^2 (which is proportional to $\Delta\chi$ at low fields) on $1/H$. The scale of ordinates is arbitrary, but the same for *a* and *b*, for *c* and *e*, and for *d* and *f*. (*a*) Nickel sulphate hexahydrate, tetragonal axis horizontal 1·61° K. (*b*) As (*a*), but at 4·19° K. (*c*) Copper potassium sulphate, (001) plane horizontal 1·68° K. (*d*) Copper potassium sulphate, *b*-axis vertical 1·66° K. (*e*) As (*c*) but at 4·19° K. (*f*) As (*d*) but at 4·19° K.

The measured anisotropies are related to χ_1, χ_2, χ_3 (using standard notation—see for instance, Krishnan and Mookherji, 1938; Bose, 1948) by

$$(\Delta\chi) = (\chi_1 - \chi_2)$$

$$(\Delta\chi)' = (\chi_1 - \chi_3) - (\chi_1 - \chi_2)\cos^2 94^\circ$$

and the χ's are related to $K_\parallel - K_\perp$ (the 'ionic' anisotropy) by

$$K_\parallel - K_\perp = 2(\chi_1 - \chi_2) - (\chi_1 - \chi_3)$$

so we obtain finally

$$K_\parallel - K_\perp = \frac{15{\cdot}6\times 10^{-2}}{T} - \frac{3{\cdot}6\times 10^{-2}}{T^2} \quad \ldots \quad (27)$$

to which of course a small constant term C can be added, which is negligible in our range of temperatures but may be appreciable at higher temperatures.

Now at 84°K., S. K. Dutta (unpublished) finds $K_{\parallel}-K_{\perp} = 1{\cdot}88\times10^{-3}$ while our formula gives $1{\cdot}85\times10^{-3}$ and so requires C to be $0{\cdot}03\times10^{-3}$. If we had ignored the $1/T^2$ terms above and fitted only the 4·19° K. points, we should have had $K_{\parallel}-K_{\perp} = 13{\cdot}9\times10^{-2}/T$ which would give $1{\cdot}65\times10^{-3}$ at 84° K. and would require C to be $0{\cdot}23\times10^{-3}$, which is much higher than indicated by measurements at higher temperatures and is moreover not very plausible theoretically. These considerations suggest, then that the $1/T^2$ terms are really required, and this is of some interest as the theory (Van Vleck, 1932; Polder, 1942) suggests that they should vanish.

Conclusions

Our results show that the anisotropic behaviour of parmagnetic crystals at low fields in the liquid helium range is on the whole reasonably consistent with extrapolation from the behaviour at temperatures above 80° K., in spite of the great gap between the two temperature ranges. For nickel sulphate there is evidence, however, that higher order terms in $1/T$ are required to describe the behaviour; such terms may very reasonably be expected, though the expansion of the theoretical formulae in powers of $1/T$ has not yet been carried far enough to permit interpretation of the numerical coefficients of these terms. The anisotropy at high fields shows marked saturation effects, which agree in their orientational dependence with the formal theory developed in this paper, but cannot be interpreted in more fundamental terms until the theory is developed beyond the linear term in H in the expressions for the magnetization.

The anisotropy of shape proves to give an accurate method of determining the form of the magnetization curve in the saturation region, though the absolute values of magnetization have to be fixed by other considerations. The saturation curves of potassium chrome alum at widely different temperatures are in excellent agreement with theory and earlier experimental data, while those for nickel sulphate hexahydrate have been measured for the first time. The temperature dependence of the low field susceptibility of nickel sulphate hexahydrate as determined by the shape method suggests a discrepancy of detail with the theoretical formula.

It seems then from this exploratory investigation that measurements by the torque method in the liquid helium region can supply much useful information about ionic paramagnetism, and in particular decide questions about the theoretically important form of temperature variation rather better than is possible at higher temperatures. The accuracy could easily be improved by using less stiff torsion wires for the low field measurements, and it would be of interest to extend the measurements to a wider range of salts. The usefulness of the high field measurements is at present limited by the lack of the necessary theoretical background, but once this is remedied, the information which can so easily be obtained about saturation effects both in the anisotropy and in the magnetization itself should certainly provide new data about the details of the crystalline field.

It is a pleasure to thank Mr. J. S. Dhillon, M.Sc., for his valuable help in these experiments.

Summary

Measurements of the magnetic behaviour of 3 paramagnetic crystals (potassium chrome alum, nickel sulphate hexahydrate and copper potassium sulphate) have been made by the torque method at liquid helium temperatures in fields up to 28 KG. The

formal theory relating the torque to the field and its direction relative to axes in the crystal has been extended to cover saturation effects and shape effects. The experimental results confirm this formal theory and from the shape effects in potassium chrome alum and nickel sulphate hexahydrate the magnetization curves could be deduced. It was found also that the second of these salts showed a strong anisotropy at high fields (associated with saturation effects) in the plane normal to the tetragonal axis. The magnetic anisotropies of nickel sulphate hexahydrate and copper potassium sulphate also showed saturation effects; at lower fields the temperature variation of the anisotropies was in fair agreement with extrapolation of results at much higher temperatures, but higher order terms in $1/T$ (which are negligible at higher temperatures) were also in evidence. These results are discussed in relation to the crystalline field theory.

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Note added in proof

Professor M. H. L. Pryce has drawn our attention to a paper (Griffiths, J. H. E., and Owen, J., 1952, *Proc. Roy. Soc.* A, **213**, 459) in which it is pointed out that the formulae given by Schlapp and Penney require slight modifications. These have the effect of considerably altering the estimate of λ mentioned in the text (from $-480k$ to about $-360k$) and consequently also of the other parameters. The qualitative conclusion that the sign of the $1/T^2$ term in (21) is inconsistent with the assumption of tetragonal symmetry for the crystalline field is not, however, affected.

II. NATURAL SELECTION

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INTRODUCTION

The theory of evolution is one of a group of scientific theories as to the remote past, the others being geology and cosmology. Both these latter are based on calculations as to the effects, over millions of years, of processes observable in the present, and well studied, such as erosion, vulcanism, radioactivity, gravitational attraction, radiation, and so on. Thanks to palaeontology, many of the facts of evolution are as well established as those of historical geology, and much better than those of cosmology. We know for example that some of the primitive amphibia had long tail fins like those of fish, that is to say they kept their tail fins after their pectoral and pelvic fins had been transformed into legs. We know that the mammalian type of wrist and ankle evolved before the middle ears were transformed, and so on.

But Darwin held, and I agree with him, that evolution was largely brought about by natural selection. No quantitative observations of natural selection had been made in Darwin's time, and this enabled his opponents to state that no-one had observed natural selection. It has since been observed and measured, but as we shall see, the process observed is not very like what Darwin imagined.

One reason is as follows. Evolution of a quantitative character is usually very slow. For example during 50 million years or so, the teeth of ancestral horses grew longer. The mean increase in length was about 4% per million years. Doubtless the increase was somewhat irregular. But an increase of a thousand times this rate would be only 0·4% in a century, and this would not be noticed in a wild population.

Observations on artificial selection show that the efficiency of this process, which can be measured by the change in a mean per generation divided by the mean excess of the parents over the population from which they were selected, is sometimes 50%, and often over 20%. If mice 10 gms. heavier than the average of a population are selected as parents we expect their young to average 2 or 3 grams above the children of unselected parents. Thus an increase of ·02% per generation might involve a difference of ·1% between the parents of the next generation and the population from which they were selected naturally. Such differences cannot be observed in men, let alone wild animals or plants.

We can only hope to observe natural selection in two cases. Firstly if an animal is placed in a new environment which exercises intense selection. Secondly, if selection is balanced by some other agency.

Evolutionary changes have occurred through human intervention. For example when scale insects such as *Aonidiella* were subjected to HCN fumigation in orange groves in California, resistant races evolved. Clearly the process was not observed. An economic entomologist who observed a single insect surviving on a tree after fumigation would not carefully preserve it and breed from it! He would kill it mechanically.

Similarly races of various insects immune to other insecticides are evolving. Laboratory experiments show that this is at least largely due to selection. One can obtain resistant stocks by breeding from survivors. Here a Lamarckian effect could be involved. One can also do so by breeding from a number of pairs of insects, and subsequently testing these parents. The next generation is bred from families whose parents have survived. A Lamarckian effect is therefore excluded. In such cases as this, and the melanism of many Lepidopteran species in industrial areas, natural selection can be inferred with high probability. It cannot be observed in the field.

Three main agencies can balance natural selection. These are mutation, migration, and segregation. It is at first sight a remarkable fact that the most accurate data on natural selection are data on men. When, however, we consider the extreme difficulty of following an individual wild animal through its life, this is not perhaps surprising. It is true that a good deal is known as to the relative inviability and sterility of animal mutants in captivity. But much less is known as to their fitness in nature. As for plants, we can estimate their viability and seed production, but it is even harder to estimate the efficacy of a plant as a pollinator than that of an animal as a father.

It can of course be objected to the human data that human beings live in environments of their own making; even primitive hunting tribes make shelters. However, I do not see that a human city is any less 'natural' than an ant's or termites' nest. A species should surely be studied in its normal environment.

I have summarized the literature on human mutation (Haldane, 1949). Several dominant and sex linked recessive characters are known which constantly reappear by mutation, but are seldom inherited for many generations. Thus the fitness of haemophilics, measured by comparing the mean number of children begotten by them with the mean for the people amongst whom they live, is about 0·25. This is largely due to early death. About half of all haemophilics were dead before the age of 15 years in the United States, and 18 years in Denmark. Achondroplasic dwarfs are even less fit. But epiloia (Bourneville's disease) does not seem to be so serious. It is only fatal when the characteristic tumours are formed in such an organ as the heart or kidney. When they are formed in the brain it causes mental defect of varying degree which often leads to sterility. Perhaps it halves the fitness. Other dominant conditions may reduce fitness by as little as 10%. But in every case a steady state is fairly quickly reached in which as many dominant or sex-linked recessive genes are destroyed in each generation as appear by mutation. Autosomal recessives do not reach a steady state at all rapidly. Indeed after a disturbance it may take 25,000 years or so to return half way to equilibrium.

Where a cline exists, that is to say, the mean colour or form of a species alters gradually from one region to another, there is often reason to think that selection is balanced by migration; but this has not yet been proved conclusively in any particular case.

The most striking cases of natural selection are those where it is balanced by segregation. At certain loci heterozygotes are fitter than homozygotes. For example, in man the genotype Si Si has normal haemoglobin. si si has a haemoglobin which is insoluble when reduced. The corpuscles in the venous blood assume distorted forms, and such persons generally die of sickle-cell anaemia before puberty. The heterozygotes Si si have a mixture of the two haemoglobins. They do not become anaemic, but are immune to malignant tertian malaria caused by *Plasmodium falciparum*. According to Allison (1954) they may be over 10% fitter than Si Si in tropical Africa. If men reproduced clonally, like banyan trees or aphids, almost the whole population would come to

consist of Si si. In fact Si si individuals mated with any genotype produce 50% Si si only. This segregation prevents natural selection from being fully effective, and the frequency of heterozygotes never rises above 40%.

Quantitative characters, such as stature, depend on the interaction of a number of genes with environmental agencies. These genes are rarely completely dominant. When we study a quantitative character in nature, we generally find that the extremes are less fit than those near the mean. Haldane (1953) has cited several examples. The most striking is Karn and Penrose's (1951) data on human birth weight, which has since been shown by Robson to be largely determined by maternal genes. The death rate of all babies in a sample of 13,000 born in Central London was 4½% at birth and in the first four weeks of life. Those babies who weighed between 7½ and 8½ pounds had a death rate of only 1½%. Those who were lighter or heavier than the optimum had larger death rates. Thus if all babies had been of the optimal weight only 1½% would have died. The extra 3% death rate is the effect of natural selection in weeding out extremes. Quite similar results have been obtained on various animals, including ducks (Rendel, 1943) and snails (Weldon, 1901). In these cases the main effect of natural selection is conservative. It is of course possible that natural selection is slowly changing the mean. But its main effect has been to reduce the variance in each generation.

Finally Cain and Sheppard (1954) have obtained results of a much more Darwinian character on the polymorphic snail *Cepaea nemoralis*. To mention only one result, yellow forms are commoner than brown in green grass, and much rarer in woods whose soil is covered with dead brown leaves. This is partly due to selective predation by the thrush *Turdus ericetorum*. This bird breaks snail shells on stones or logs, and thus leaves a record of its predation. In a deciduous wood in early spring yellow snails are predominantly chosen. As the leaves get greener the yellow snails are neglected in favour of the brown ones, which are now clearly more conspicuous to birds, as they are to men. Unfortunately sufficient numbers are not available to give a good estimate of the intensity of natural selection, particularly as other birds probably behave in the same way without leaving records.

This very brief survey at least makes it clear that natural selection is a reality, and what is perhaps more important, a reality which can be measured. Its main effect is to stabilize species by weeding out abnormal individuals of various kinds. In most situations only a tiny fraction of the selection which occurs has any evolutionary effect.

It is clear that a great deal could be done in India on similar lines, particularly because little apparatus is required. For example it would not be hard to find out whether, in poultry and ducks which have not been selected for egg laying, the light and heavy eggs produce fewer living chickens than those of medium weight. Polymorphic animals of various classes exist in India, which could be studied. It is not for me to suggest suitable objects of study. I can, however, state that work of this kind is very rapidly becoming fashionable in North and South America as well as Europe.

Perhaps for a century biologists have been almost spell-bound by Darwin. I yield to few in my admiration of him. But just because I think that his theory of evolution is probably true, I believe that it should be checked at every possible point. A quantitive study of natural selection under as many different conditions as possible is a pre-requisite to any theory of evolution which will have the logical validity of the theories of physics.

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III. THEORY OF DIRECT INTERACTIONS IN NUCLEAR REACTIONS

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§ 1. INTRODUCTION

It has been found suitable that nuclear reactions are, even at low energies, interpreted in terms of a direct interaction between nucleons in a number of cases. Among these the stripping reaction of deuterons has successfully been analyzed along this line by Butler [1] and others. Indications on the direct interaction have also been noticed in photo-nuclear reactions [2] and nucleon scattering problems.[3] In these treatments the direct interaction is considered to take place chiefly at or near the surface of nuclei, since a nucleon knocked out near the centre of a nucleus is thought to be rescattered in the same nucleus and results in a complicated nuclear excitation. This assumption seems open to question, however, because the analysis of neutron total cross-sections indicates small absorption [4] on one hand and some experiments show marked deviations from the prediction based on the surface interaction. Theoretical analyses of various phenomena being carried out in our country are accumulating such evidences.

In treating the above problems it is of decisive importance to recognize the extent of approximations to which one refers. To clarify the meaning of approximations a number of papers [5] have been published, concerning the stripping reaction, but few quantitative results have yet been obtained. Most of these works are of limited use, since an arbitrary nuclear potential is assumed *ab initio*, so that the interaction only outside a nucleus is taken into consideration.[6] For wider applicability suitable to our purpose, we need to formulate the problem in a fundamental way.

In this paper we give the formalism of dealing with the direct interaction with regard to the nucleon scattering and the stripping or pick-up reaction. The formulation is presented as simple as possible, for emphasizing physical implications, and the applications to practical problems are left to the forthcoming papers which will be published in the *Progress of Theoretical Physics*. Accordingly, the effects, that make formulas complicated, such as Coulomb forces and nucleon exchanges, are neglected. The interaction with the surface oscillation is not explicitly given either. We also skip the expression of partial waves, since it is readily derived, if needed.

§ 2. SEPARATION OF SINGLE PARTICLE STATE

In order that a particular nucleon in a nucleus is regarded as taking part in the direct interaction, the motion of the nucleon has to be separated out of the rest. This consists in the assumption of the single particle model, in which a nucleon moves in an optical potential. The optical potential can be constructed through the multiple scattering of a nucleon, as has been worked out by Francis and Watson [7], and, consequently, it is in general an energy dependent quantity. For our purpose, however, it is more convenient to introduce such a potential that is energy independent and coincides with the optical potential at a certain energy. The energy may be taken as such at which reactions occur.

But we rather prefer to choose a smeared potential that is the potential energy of the particular nucleon against a core. Then there arises an interaction that cannot be expressed in the form of such a smeared potential. This may be interpreted as the interaction with the nuclear core that consists of nucleons other than the particular one.

Along this line the Hamiltonian for the whole nucleus composed of A nucleons is decomposed into three parts:

$$H_t = H_1 + H_c + H_{1c}. \qquad (2.1)$$

Since we discard the exchange effect in this paper, this decomposition separates nucleon co-ordinates, too.

H_1 consists of the kinetic energy of the particular nucleon, designated as nucleon 1, and the potential energy assumed above, which is a function of the co-ordinate of the nucleon 1, $\mathbf{r}_1$, alone:

$$H_1(\mathbf{r}_1) = K_1 + U_1(\mathbf{r}_1). \qquad (2.2)$$

H_c is the Hamiltonian for the core and is expressed as the sum of the kinetic energies of the residual $A-1$ nucleons and of the potential energies between pairs of them, provided that there exist only two body forces [8]:

$$H_c(\mathbf{r}_2, \ldots, \mathbf{r}_A) = \sum_{i=2}^{A} K_i + \tfrac{1}{2} \sum_{i,j \geqslant 2} V_{ij}(\mathbf{r}_i, \mathbf{r}_j). \qquad (2.3)$$

H_{1c} represents the interaction between the nucleon 1 and the core:

$$H_{1c}(\mathbf{r}_1; \mathbf{r}_2, \ldots, \mathbf{r}_A) = \sum_{i=2}^{A} V_{1i}(\mathbf{r}_1, \mathbf{r}_i) - U_1(\mathbf{r}_1). \qquad (2.4)$$

U_1 is subtracted, since this is already taken into account in H_1. The expectation value of H_{1c} should vanish at an energy, at which U_1 is determined. This is not necessarily the case, because U_1 may be chosen as a simple but approximate one. However, the matrix element of H_{1c} is supposed to be small in most cases, since the great part of interactions between the nucleon 1 and the core is already implied in U_1.

In describing single particle states it is convenient to refer to a set of eigen states of the core obeying the eigen value problem

$$(\epsilon_\gamma - H_c)\chi_\gamma(\mathbf{r}_2, \ldots, \mathbf{r}_A) = 0, \qquad (2.5)$$

ϵ_γ is an energy level corresponding to an eigen state χ_γ. The wave function for the whole nucleus with energy E_τ, satisfying

$$(E_\tau - H_t)\Phi_\tau = 0, \qquad (2.6)$$

is expanded as

$$\Phi_\tau(\mathbf{r}_1, \ldots, \mathbf{r}_A) = \sum \phi_\gamma^\tau(\mathbf{r}_1)\chi_\gamma(\mathbf{r}_2, \ldots, \mathbf{r}_A). \qquad (2.7)$$

The coefficient ϕ_γ means the probability amplitude for the core to be in a state γ. Due to the orthonormality of Φ_τ and χ_γ, ϕ_γ is normalized as

$$\int \sum_\gamma \phi_\gamma^{\tau *}(\mathbf{r}_1)\phi_\gamma^{\tau'}(\mathbf{r}_1)d\mathbf{r}_1 = \delta_{\tau\tau'}. \qquad (2.8)$$

Introducing (2.7) into (2.6) and taking account of (2.1) and (2.5), there results

$$(E_\tau-\epsilon_\gamma-H_1)\phi_\gamma^\tau=\sum_{\gamma'}W_{\gamma\gamma'}^{(1)}\phi_{\gamma'}^\tau, \qquad \text{.. .. ..} \quad (2.9)$$

with

$$W_{\gamma\gamma'}^{(1)}(\mathbf{r}_1)=<\gamma\,|\,H_{1c}\,|\,\gamma'>. \qquad \text{.. .. ..} \quad (2.10)$$

Now one can see that ϕ_γ describes the behaviour of the nucleon 1. If (2.9) is made to be a diagonal form, one can get a single particle description. However, we maintain the form (2.9) and interpret $W^{(1)}$ in appropriate ways.

When there is a nucleon impinging on the nucleus, we can readily extend the above formulation as follows. The impinging nucleon with co-ordinate $\mathbf{r}_0$ is designated as nucleon 0. This nucleon can also be regarded as to move in a smeared potential provided by the target nucleus, but we consider such a potential only against the core, treating the interaction with nucleon 1 separately. Accordingly, the Hamiltonian for the total system composed of the impinging nucleon and the target is expressed as

$$H=H_0+H_t+V_{01}+H_{0c}, \qquad \text{.. .. .. ..} \quad (2.11)$$

where H_t is given in (2.1).

H_0 is the Hamiltonian for the nucleon 0, and is given, analogous to H_1, by

$$H_0(\mathbf{r}_0)=K_0+U_0(\mathbf{r}_0). \qquad \text{.. .. .. ..} \quad (2.12)$$

U_0 is the potential against the core and may be equal to U_1 numerically.

H_{0c} is the interaction between the nucleon 0 and the core, but U_0 is subtracted:

$$H_{0c}(\mathbf{r}_0\,;\,\mathbf{r}_2,\ldots,\mathbf{r}_A)=\sum_{i=2}^{A}V_{0i}(\mathbf{r}_0,\mathbf{r}_i)-U_0(\mathbf{r}_0). \qquad \text{.. ..} \quad (2.13)$$

Analogous to (2.10), we introduce

$$W_{\gamma\gamma'}^{(0)}(\mathbf{r}_0)=<\gamma\,|\,H_{0c}\,|\,\gamma'>. \qquad \text{.. .. .. ..} \quad (2.14)$$

$V_{01}(\mathbf{r}_0,\mathbf{r}_1)$ is the direct interaction between the nucleons 0 and 1, playing a main rôle in our problem.

The wave function for the total system, Ψ_a, which satisfies

$$(\mathcal{E}_a-H)\,\Psi_a=0. \qquad \text{.. .. .. ..} \quad (2.15)$$

for energy $\mathcal{E}_a$, is expanded with respect to the states of the target nucleus as

$$\Psi_a(\mathbf{r}_0,\ldots,\mathbf{r}_A)=\sum_\tau\psi_\tau^a(\mathbf{r}_0)\,\Phi_\tau(\mathbf{r}_1,\ldots,\mathbf{r}_A). \qquad \text{.. ..} \quad (2.16)$$

Then there results

$$(\mathcal{E}_a-E_\tau-H_0)\psi_\tau^a=\sum_{\tau'}\left[\sum_\gamma<\phi_\gamma^\tau\,|\,V_{01}\,|\,\phi_\gamma^{\tau'}>+\sum_{\gamma\gamma'}W_{\gamma\gamma'}^{(0)}<\phi_\gamma^\tau\,|\,\phi_{\gamma'}^{\tau'}>\right]\psi_{\tau'}^a. \quad \text{..} \quad (2.17)$$

This equation reveals the interactions of the nucleon 0 with the nucleon 1 and the core.

§ 3. Scattering of Nucleon

Equation (2.17) allows us to calculate the scattering amplitude for a nucleon. As the Lippmann-Schwinger formalism [9] is used for its simplicity of writing, we start from the following form of equation

$$(\mathcal{E}_a-K_0-H_t)\Psi_a=(U_0+V_{01}+H_{0c})\Psi_a. \qquad \text{.. .. ..} \quad (3.1)$$

The Hamiltonian terms appearing in the right hand side vanishes, when the nucleon is separated infinitely far from the target nucleus. Hence the initial state is described by the product of a plane wave with a given momentum and an eigen state of the target nucleus as

$$F_a = f_a(\mathbf{r}_0)\Phi_a, \quad \cdots \quad (3.2)$$

where both the momentum and the eigen state are indicated by a common suffix a. With this initial state the scattered state is written as

$$\Psi_a^{(+)} = F_a + \frac{1}{\mathcal{E}_a - K_0 - H_t + i\eta}(U_0 + V_{01} + H_{0c})\Psi_a^{(+)}, \quad \cdots \quad (3.3)$$

where η is a small positive, introduced to indicate the outgoing wave.

Denoting the final state, in which the nucleon is of a given momentum and the residual nucleus is left in an eigen state, both being designated by a common suffix b, as

$$F_b = f_b(\mathbf{r}_0)\Phi_b, \quad \cdots \quad (3.4)$$

the transition matrix for $a \to b$ is given by

$$R_{ba} = \langle F_b | U_0 + V_{01} + H_{0c} | \Psi_a^{(+)} \rangle. \quad \cdots \quad (3.5)$$

There holds the energy conservation between the initial and the final states

$$\mathcal{E}_b = K_b + E_b = K_a + E_a = \mathcal{E}_a. \quad \cdots \quad (3.6)$$

In reducing the formal expression (3.5) to a tractable one, we introduce a wave distorted by U_0, that is

$$G_a^{(+)} = g_a^{(+)}\Phi_a = F_a + \frac{1}{\mathcal{E}_a - K_0 - H_t + i\eta} U_0 G_a^{(+)}. \quad \cdots \quad (3.7)$$

U_0 is responsible to distort the nucleon wave into $g_a^{(+)}$, but is nothing to do with the nuclear state Φ_a. The use of the distorted wave is advantageous and practical, because it is better than the plane wave employed in the Born approximation and $g^{(+)}$ is actually obtainable, provided that U_0 is of a simple form, say, a square well. For the evaluation of the transition matrix we need to use the ingoing wave, as has been emphasized in many occasions. This is given, for the final state, by

$$G_b^{(-)} = g_b^{(-)}\Phi_b = F_b + \frac{1}{\mathcal{E}_b - K_0 - H_t - i\eta} U_0^\dagger G_b^{(-)}, \quad \cdots \quad (3.8)$$

where $U_0^\dagger$, the complex conjugate of U_0, is used for allowing us to employ a complex potential, if needed.

Eliminating F_b from (3.5) with use of (3.8), and on account of (3.3), (3.6) and (3.5) is reduced to

$$R_{ba} = \langle G_b^{(-)} | V_{01} + H_{0c} | \Psi_a^{(+)} \rangle + \langle G_b^{(-)} | U_0 | F_a \rangle. \quad \cdots \quad (3.9)$$

The last term means the elastic scattering due to U_0 and is further reduced, with the orthonormality of Φ_γ, to

$$\langle G_b^{(-)} | U_0 | F_a \rangle = \langle g_b^{(-)} | U_0 | f_a \rangle \delta_{ba}. \quad \cdots \quad (3.10)$$

showing manifestly the elastic character. The first term in the right hand side of (3.9) may be expressed in a dispersion formula by reducing it to a surface integral, but we

regard the first order term in $V_{01}+H_{0c}$ as the main one, according to our purpose for emphasizing the direct interaction. Hence we approximate

$$<G_b^{(-)}|V_{01}+H_{0c}|\Psi_a^{(+)}> \cong <G_b^{(-)}|V_{01}+H_{0c}|G_a^{(+)}>$$

$$=\sum_{\gamma}<g_b^{(-)}\phi_\gamma^b|V_{01}|g_a^{(+)}\phi_\gamma^a>+\sum_{\gamma\gamma'}<g_b^{(-)}|W_{\gamma\gamma'}^{(0)}|g_a^{(+)}><\phi_\gamma^b|\phi_{\gamma'}^a>. \quad \text{.. (3.11)}$$

In the last expression as well as in (3.10), wave functions $g_a^{(+)}$ and $g_b^{(-)}$ are obtainable for given U_0 and U_1 and ϕ_γ may be well approximated by single particle wave functions, since $W_{\gamma\gamma'}^{(1)}$ in (2.9) is supposed to be small. Then we are allowed to evaluate the transition matrix unambiguously, provided that V_{01} and $W_{\gamma\gamma'}^{(0)}$ are known.

In the last expression of (3.11) we evaluate the first term that is to correspond to the direct interaction in the nucleon scattering. Assuming the zero range for V_{01}, Hayakawa and Sasakawa [10] examined the contribution of overlapping of the wave functions with respect to radial distances. The results obtained are summarized as follows. (1) The overlapping outside the nuclear surface gives only a part of contribution to the transition matrix, so that the assumption by Austern *et al.*[8] to take the overlapping only outside the nucleus is questionable. The greater contribution is found to come from inside than outside at nucleon energies of several to several tens Mev. (2) There appears a maximum (not the largest) of the overlapping at a little greater distance than the radius of the square potential well. This indicates that the nuclear radius deduced from nuclear reactions is a little larger than the radius of the nucleon configuration. The position of the maximum is found to depend strongly on the binding energy. This qualitatively explains the characteristic fluctuation of reaction radii for light nuclei in terms of that of binding energies. Furthermore, the broad maximum in total neutron cross-sections is expected at the incident energy close to the binding energy of the last nucleon, in accordance with experiments.[11]

The term containing $W_{\gamma\gamma'}^{(0)}$ in (3.11) is shown to be expressed as the interaction with the collective oscillation of a nucleus.[12] This effect is presumed to be of considerable importance for medium weight and heavy nuclei, for which the surface interaction is supposed to be predominant on various experimental grounds.

§4. Deuteron Stripping Reactions

Slight modifications of the foregoing formalism are needed for the extension to the stripping and the pick-up reactions. As these two are mutually reciprocal processes, we shall only be concerned with the former.

Now the initial state of energy $\mathcal{E}_d$ consists of a deuteron of a given kinetic energy and a target nucleus in an eigen state of the core, in the language of §2 and §3. Representing these two quantities by a common suffix d, the initial wave function is

$$F_d=\varphi_d(r_0, r_1)\chi_d. \quad \text{.. .. .. .. (4.1)}$$

φ_d describes the internal motion of the dueteron as well as the translational motion with the given momentum and is an eigen function of the Hamiltonian

$$H_d=K_0+K_1+V_{01}. \quad \text{.. .. .. .. (4.2)}$$

With this initial state the outgoing wave solution is obtained as

$$\Psi_d^{(+)}=F_d+\frac{1}{\mathcal{E}_d-H_d-H_c+i\eta}(U_0+U_1+H_{0c}+H_{1c})\Psi_d^{(+)}. \quad \text{.. .. (4.3)}$$

From this we can extract an asymptotic wave described by F_b in (3.4) and obtain the transition matrix [13]

$$R_{bd} = <\Psi_b^{(-)} \mid U_0+U_1+H_{0c}+H_{1c} \mid F_d> = <F_b \mid U_0+V_{01}+H_{0c} \mid \Psi_d^{(+)}>, \quad .. \quad (4.5)$$

where $\Psi_b^{(-)}$ is the ingoing wave induced by F_b. Introducing the distorted wave of the incident deuteron by

$$G_d^{(+)} = F_d + \frac{1}{\mathcal{E}_d - H_d - H_c + i\eta}(U_0+U_1)G_d^{(+)} \ , \quad .. \quad .. \quad (4.6)$$

(4.5) is reduced, after algebraic manipulations, to

$$R_{bd} = <\Psi_b^{(-)} \mid H_{0c}+H_{1c} \mid G_d^{(+)}> = <G_b^{(-)} \mid V_{01}+H_{0c} \mid \Psi_d^{(+)}>. \quad .. \quad (4.7)$$

These expressions may be approximated in a number of ways. However, we do not go into this point, but leave it for later occasions.

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IV. FUNDAMENTAL APPROACH TOWARDS MALARIA CHEMOTHERAPY

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The subject of malaria and the malarial parasites is one of the most common medical topics, but in view of the recent developments in malariology, a fresh discussion on the above may be of considerable interest. The disease is caused by the genus *Plasmodium* that exhibits two cycles of developments, an asexual and a sexual. The former parasites go through a period of growth inside the red corpuscles of human blood and the latter through a cycle of development in the body of the mosquito. There are about 1,700 species of all kinds of mosquitoes but it is only the anophelines that carry the malarial parasites. Measures are now being taken to destroy the latter (not more than 170 species) in the larval or aquatic stages in the breeding grounds rather than fight a rear-guard action against the winged insect near the dwelling places. In any such control the antimalarial drugs will also play an important rôle in combating the malarial disease, particularly in the following circumstances (W.H.O., 1954): (*a*) where any factor precludes the application of antimosquito measures or renders the response to them unsatisfactory; (*b*) where residual spraying has been discontinued but there is still need to deal effectively with relapsing cases or infected immigrants; and (*c*) where malaria has appeared in an epidemic form.

Way of Attack

Extensive investigations are already on record for the evaluation of a suitable antimalarial and we have now very good suppressive agents in 4-aminoquinolines (I). But the modern trend in chemotherapeutic research is to elaborate a specific chemical agent that may attack the malaria problem at its vital point of the sporozoite (infecting) development stage in the same way as it has succeeded in attacking the schizogony by 4-aminoquinoline or quinine and gemetogony cycle by 8-aminoquinolines of the type (II). For any such success we must have a clear picture of the intricacies of the life-cycle of the parasites in the human system. It is known that the sporozoites (infecting stage of the parasites) in the human blood soon pass to liver tissues. Knowledge of their catalytic system, that is affording the source of energy, is scanty; otherwise it might have been possible to stop or alter the above catalytic phenomenon in order to starve to death the parasite even in the presence of tissues. The wood-eating termite, for example, harbours an intestinal messmate (an endamœba) whose catalysts can convert the wood into substances which the termite can utilize as food. The function of the endamœba may be stopped by increasing the oxygen pressure. This will not directly affect the termite but the termite starves to death on a diet of wood. If it be possible to know how the catalytic changes are involved in the life-cycle of the sporozoites of the malarial parasites, ways and means might similarly be found out for stopping the above catalytic reaction and thereby, their survival in the human system. This naturally needs a study of the biological characteristics of malarial parasites.

Present Knowledge

If a survey be made on the nature and behaviour of the existing antimalarials, it will be found that quinine, the oldest drug, exerts more pronounced action on the schizonts of

Plasmodium falciparum, whereas the 4-aminoquinolines (I) are more effective in the treatment of vivax (benign tertiary) malaria. In the latter case a still better result might be obtained by judicial ingestion of an 8-aminoquinoline (II) with quinine. The question is why are there such differences in behaviour? For better understanding an idea on the host-parasite relationship in the presence of an antimalarial drug must be gathered. As the sporozoites remain in the circulatory system only for a couple of days (*cf.*, Shortt, 1950), it would be difficult to arrest its development and/or to create conditions uncongenial for their very existence unless we know the basic nature of their metabolism. Researches in this direction tend to suggest (*cf.* Coggeshall and Maier, 1941; Speck and Evans, 1945; Christopher and Fulton, 1948; Silverman *et al.*, 1944; Moulder, 1948 and Marshall, 1948) that the suppression of the growth of the malarial parasites in the presence of the drugs is due to the inhibition of their oxygen consumption and this phenomenon is more pronounced *in vivo*. Considering that the change might be due to the presence of some metabolic products of the drug, search for the isolation of one or other more active metabolic degradation product from the known antimalarials has been made, but in vain. This has, however, given rise to newer thought and has directed attention of the workers in the field to newer channels. For example, Carrington *et al.* (1951) noted that a triazine derivative found in the urine of the animals treated with paludrine, is the active substance responsible for the characteristic antimalarial property of paludrine. This observation had helped in the study of another dihydrotriazine derivative that is being found to be a cheap and easily tolerated suppressive drug in the treatment of vivax malaria (*vide infra*).

Mode of Action

For the last few years work on biological studies on malarial parasites is in progress in this laboratory (*cf.* Dutta and Basu, 1953). In course of this work an interesting observation has been made that the inhibiting action of quinine or other quinoline derivatives on the oxidation of α-ketoglutarate to succinate present in the enzymes of the tricarboxylic acid cycle of the malarial parasites is reversible in presence of equimolecular concentration of BAL or sulphuretted hydrogen water.

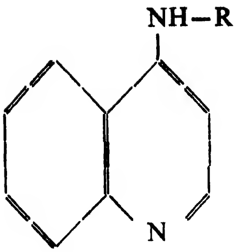
It is known that life involves the direction of chemical change by the basic catalytic units, together with self-duplication. For creating any non-existent conditions of life the basic biocatalysts are to be changed to a degree that resumption of active life becomes impossible. A study in any such direction needs a knowledge of the make-up of the protein molecules that are associated with the life-process and that of nucleo-proteins which represent the core of the chemical reactivity in the living cell. Further, as the formation of nucleic acids appears to be closely associated with the process of protein synthesis, a work on the make-up of the nucleic acid of malarial parasites at different stages of their life-cycle seems to be of considerable significance. Certain investigations in the above direction are already in progress (*cf.* Chen, 1944; Deane, 1945; Whitfeld, 1952 and Lewert, 1952*a*). The type of nucleic acids present in the parasites seems to vary with the growth of the cells—the nuclei of the mature schizont and of the merozoites containing maximum amount of desoxyribonucleic acid (DNA) and that of gametocytes containing the least (*cf.* Bishop, 1954). Naturally, inhibition of the factor or factors responsible for the synthesis of nucleic acids may retard the schizogony process of the parasites. As a matter of fact it is found that the drugs that exert an inhibitory influence on the formation of folic acid essential for the formation of nucleic acids, are schizonticidal in character. Lewert (1952*b*) noticed a lower level of nucleotides as well as

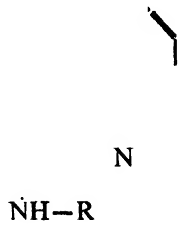
a decrease in proteins in parasites treated with paludrine, a known folic acid antagonist. Further, Haas (1944) from his study on some antimalarials on respiratory enzymes found that mepacrine (IV) produces a pronounced inhibition of cytochrome reductase, the prosthetic group of which contains riboflavin. Seeler and Ott (1944) again have shown that riboflavin is an essential metabolite for *Plasmodia*. The structural resemblance of quinine (V) and mepacrine to riboflavin (VI) may account for their activity against the schizonts of the malarial parasites (*cf.* also Madinaveitia, 1946). Wright and Sabine (1944) have actually noticed an inhibition of flavin enzyme-D-amino-acid oxidase. All these suggest a competition between the above drugs and the prosthetic group of the enzyme for the protein (*cf.* Hellerman *et al.*, 1946). It is to be noted that various other antibacterial substances like proflavin, 5-aminoacridine, mercuric chloride or even penicillin are not antagonized by riboflavin and exert no antimalarial activity too.

Newer Thought

The gametes of the malarial parasites are again not affected by the folic acid antagonists. On the contrary observations of MacKerras and Ercole (1948) tend to show that treatment with paludrine in patients infected with *P. vivax* produces more gametocytes than in those treated with quinine or mepacrine. This points to the necessity of a detailed study of the biological activity of the normal cell constituents of the gametocytes and the changes involved in its nucleic acid contents under the influence of drugs.

The nucleic acids present in malarial parasites (*cf.* Whitfeld, 1952) are similar to those of other organisms—the RNA content being about twice the DNA content. The purine and pyrimidine bases—cytosine, uracil, thymine, guanine, adenine, etc., are the usual constituents of nucleic acids. On the general hypothesis of biological activity of a compound, a metabolic antagonism may then be found in suitably designed pyrimidine derivatives. These have actually been noticed in many compounds, notably in pyrimethamine (VII). The product is highly active in rendering gametocytes incapable of attaining full development in the mosquito. This characteristic is of considerable significance. The synthesis of paludrine was also based on the above antagonism hypothesis. The latter product (a biguanide derivative) does not function as a riboflavin antagonist and its biological characteristics also differ from those of quinine and other quinoline compounds (*cf.* Dutta and Basu, 1953). Hawking (1947) showed that it did not exert any antimalarial activity *in vitro* and the observations of Carrington *et al.* (1951) established that its physiological property is due to its transformation to a dihydrotriazine (VIII). It will appear from the structural feature of (VII) that it has a resemblance with the amino-pyrimidines (constituent of nucleic acids) which as a class are recognized as having the capacity to interfere in biochemical processes associated with folic acid derivatives essential for the synthesis of nucleic acids. As a sulfa drug often potentiates the above type of schizonticidal drug, the compound, 2 : 4-diamino-1-*p*-sulphonamidophenyl-1 : 6-dihydro-6 : 6-dimethyl-1 : 3 : 5-triazine (IX) synthesized in another connection (Basu *et al.*, 1952), was screened against malarial parasites and is now being found in the form of its hydrochloride (Supazine) to behave as a non-toxic schizonticide in vivax malaria (Ray, Bose and Basu, 1954). It may, however, be noted that Dutta (1954) from this laboratory has shown that the dihydrotriazine (VIII) exhibits no inhibitory action on the enzymes of tricarboxylic acid cycle, nor does it play any part in the *in-vitro* formation of α-amylase. Much more biochemical work remains to be done in various directions before we may interlink the chemical constitution of a compound with its biological activity.





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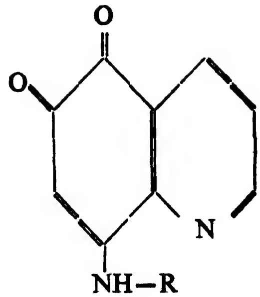
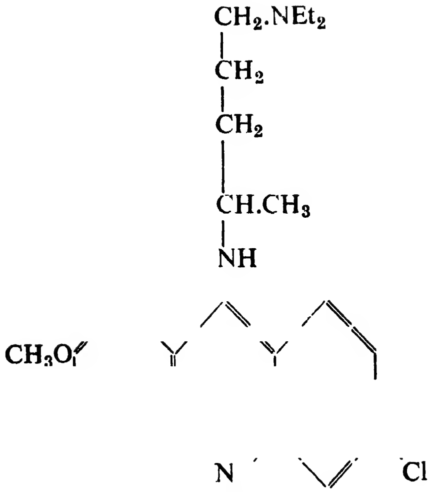


III

R = alkyl amino alkyl.



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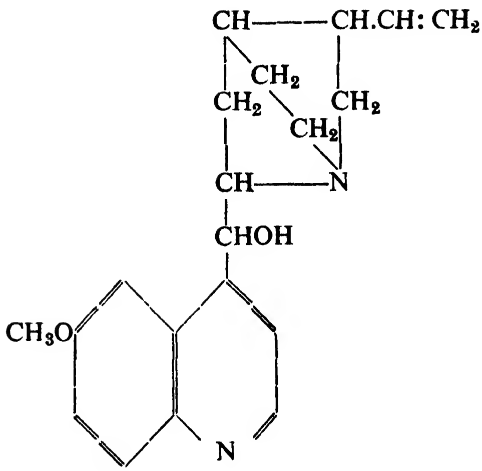
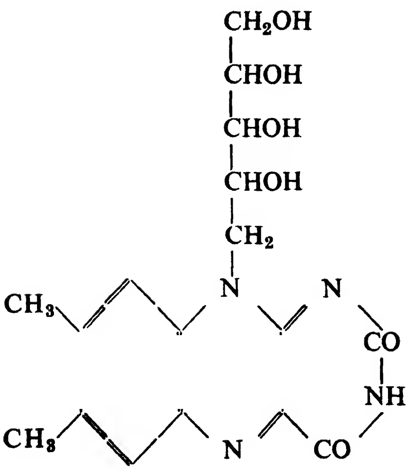
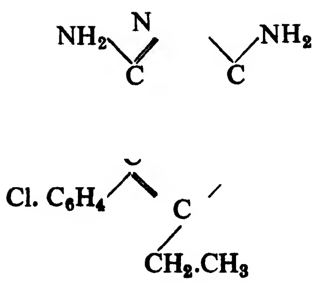


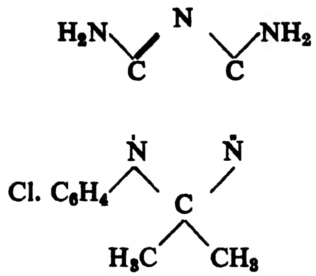
V



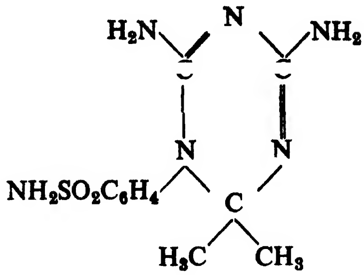
VI



VII



VIII



IX

FUTURE TRENDS

The problem that demands further extensive study is in relation to the activity of the 8-aminoquinoline (II) against the gametocytes (sexual forms) of *Plasmodium vivax*. These drugs are also not active in *in vitro* but they acquire activity on exposure to air or light, or, after some metabolic changes. The active substances are believed (*cf.*, Joshepson *et al.*, 1951) to be 5 : 6-quinoline quinone (III). Is the activity due to such formation? The parent compounds are more or less toxic and more so in cases of darker people. The question is why this is so. The analogous 4-aminoquinoline (I), chloroquin for example, undergoes a different metabolic change. The quinoline nucleus is apparently not involved, and the oxidation starts at the terminal alkylamino chain (Titus *et al.*, 1948), and has no specific action against the gametes as already recorded.

In conclusion, it may be added that no drug as yet tested has any demonstrable effect on the sporozoites when they first enter the human body. In order to exterminate the malarial parasites from the human system, a knowledge of the biological characteristics of the sporozoites as well as those of the gametocytes are essential. We yet know very little of the conditions which govern their production through the formation of macromolecules—mainly proteins and nucleic acids. As such it is difficult to speculate at the present state of our knowledge on the probable synthesis of a product that may interfere in their biological reactions either by 'neutralization' or by 'competition' or by both, and thereby, establish a non-living condition of the parasites in the living system.

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V. APPLICATION OF DIAMAGNETISM TO THE SOLUTION OF CHEMICAL PROBLEMS

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INTRODUCTION

In the Seventieth Birthday Commemoration Volume of Dr. D. M. Bose, who has made many significant contributions to the field of magneto-chemistry and is particularly well known for Bose-Stoner's formula and Bose's rule, which account for the magnetic moment of the simple and complex ions of the elements of the iron group and elucidate many problems of valency and structural chemistry, relating to these elements, I consider 'the application of diamagnetism to the solution of chemical problems' to be a very appropriate subject for discussion. Without, therefore, any further introduction I now proceed to deal with the topic I have chosen.

That there is a close relationship between the physical properties and the chemical constitution of a substance has long been recognized. Many of these physical properties, such as molecular volume and molecular refraction, were found to be *additive*; *i.e.*, they could be represented as the sum of the corresponding properties of the constituent atoms. In a similar manner, diamagnetic susceptibility of a substance was also believed to furnish an additive relationship.

PASCAL'S RULE

From a comprehensive series of measurements, extending over 1908–1914, on a very large number of organic compounds Pascal came to the conclusion that the diamagnetic susceptibility of a molecule, like the molecular refraction, can be represented by an additivity rule, and formulated the expression:

$\chi_M = \sum \chi_A + \lambda$; where λ is a constitutive correction, depending on the nature of the bonds between the atoms and on the structure of the molecule.

Pascal's rule is a purely empirical deduction with no apparent theoretical basis behind it. In spite of this, it achieved a considerable success in estimating diamagnetic corrections for paramagnetic substances, besides helping in the solution of many chemical problems relating to the constitution and structure of covalent molecules.

Pascal's atomic susceptibility constants were derived from the measurements on halogens. The constant for chlorine, or χ_{Cl} for instance, was given by half the molar susceptibility of Cl_2. From this as the basis, the atomic susceptibility of hydrogen was calculated from the difference in susceptibility values of benzene and trichlorobenzene, of acetone and monochloroacetone and that of other similar compounds. The value for the carbon atom was then deduced from that of $-CH_2$ group, derived from a consideration of the susceptibility values of the members of any homologous series. The values for other elements and the values of λ, the constitutive correction constants, were then deduced from the susceptibilities of various compounds.

Pascal's data have been found to be reliable in many cases, though the system is entirely empirical. His pioneering work has made a notable contribution towards the

analysis of molecular structure of organic compounds, except in the cases of certain substances containing both nitrogen and oxygen.

Polymerization and Association

The course of polymerization of a substance has been studied by magnetic measurements on the basis of Pascal's rule. For the formation of every new bond between two molecules, a new constitutive constant λ is introduced in the calculation for molar susceptibility. So, when n moles of a substance B react to form a polymer B_n, then $\chi_M = n\chi_B + (n-1)\,\lambda$. Hence, the susceptibility will increase with time and the relationship between χ_M and n will be a straight line.

Farquharson (*Trans. Farad. Soc.*, 1936, **32**, 219) has found an increasing diamagnetic susceptibility with increasing polymerization in the case of 2: 3-dimethylbutadiene;

$$\begin{array}{c} CH_2 = \underset{\displaystyle H_3C}{\underset{|}{C}} - \underset{\displaystyle CH_3}{\underset{|}{C}} = CH_2 \end{array} .$$

In this case, every combination between two or more molecules leads to the formation of single bonds and the disappearance of corresponding double bonds, with the result that diamagnetism increases with increasing polymerization. It has been used by the said worker for the quantitative determination of the degree of polymerization. The same investigator (*Trans. Farad. Soc.*, 1937, **33**, 824) has studied the mechanism of formation of polyoxymethylenes by the magnetic method and determined their degree of polymerization. There are cases where the susceptibilities diminish on polymer formation, depending on the nature of the bonds formed and ruptured.

The process and mechanism of association may be studied in a similar manner by the magnetic method, but the effect of association upon the magnetic property of a substance is, however, small.

Farquharson and Ady (*Nature*, 1939, **143**, 1067) have made an interesting application of the magnetic method in testing one of the fundamental assumptions of the mechanism of polymerization, which involves the formation of free radicals. They examined the course of polymerization of 2: 3-dimethylbutadiene both in the presence and absence of benzoyl peroxide as an accelerator. In the complete absence of the accelerator, there is an induction period of about 3 hours during which the diamagnetic susceptibility falls by about 13.6 per cent. The susceptibility then rises in the normal fashion as stated before. In the presence of sufficient accelerator, on the other hand, there was no period of induction and the susceptibility curve was found to rise smoothly throughout the experiment. This supported the formation of free radicals in the absence of a catalyst. Farquharson and Ady calculated the concentration of the free radicals from the fall of diamagnetism during the induction period.

Gray and Cruikshank's Method

It has already been said that Pascal's rule is based on purely empirical data. Gray and Cruikshank (*Trans. Farad. Soc.*, 1935, **31**, 1491) have developed a method in which an attempt has been made to place the constants on a theoretical basis. They have tried to relate Pascal's constants to Pauling's theoretical atomic susceptibilities and his constitutive correction constants (λ) to Van Vleck's temperature-independent high-frequency paramagnetism. For, according to Van Vleck the susceptibility of an atom in the ^1s

state is given by: $\chi_A = \chi_d + \chi_p$; where χ_d is the usual diamagnetism and χ_p is a paramagnetic term arising from the resonance between the normal and the higher energy states of the electrons in the atom. In this method, the calculation is based on the following factors:—

(*a*) Ionic diamagnetisms, calculated on the basis of a modification of Pauling's formula.

(*b*) Residual charges, due to unequal sharing of bond electrons, calculated from the dipole moment of the bonds.

(*c*) Bond depression of diamagnetism, which, according to these authors, is partly, to a small extent, real lowering of pure diamagnetism, but mainly masking (without lowering) of pure diamagnetism by the development of high frequency paramagnetism, as indicated by quantum mechanical calculations for the simple molecule of hydrogen.

(*d*) Resonance between possible structures for the molecule, each resonating form contributing its due share to the diamagnetism of the resultant molecule.

(*e*) Formation of hydrogen bond, where hydrogen bridges are possible.

Clow and co-workers (*Trans. Farad. Soc.*, 1937, **33**, 381, 894; 1940, **36**, 1018) have reported remarkable agreements between the experimental values and those calculated on the basis of Gray and Cruikshank's method in the cases of urea and its derivatives, organic sulphur compounds, and some derivatives of sulphates, thiosulphates, etc. But the results are open to criticism (*cf.* Siddhanta and Rây, *J. Indian Chem. Soc.*, 1943, **20**, 360). The validity of the method was tested by the latter workers in the case of some simple organic molecules containing nitrogen, for which Pascal's method gives values differing widely from the experimentally determined ones. The compounds examined were dicyandiamide, acetamide and cyanuric acid, the details of whose structures were definitely known from X-ray measurements. The results, however, did not furnish a consistent and satisfactory agreement in all cases.

The question of phototropy and photochemical isomerism has been studied from the measurement of diamagnetic susceptibility by Bhatnagar and co-workers (*J. Indian Chem. Soc.*, 1938, **14**, 573), but with no definite results.

An interesting application of diamagnetic study has been made by Bauer and Raskin (*Nature*, 1936, **138**, 801), who observed a change of diamagnetism on the death of living cells. Bauer has suggested that life depends on an excited state of protein molecules in the protoplasm. Hence, on death the paramagnetic component of susceptibility (χ_p) should diminish. In yeast cells and in certain bacteria like *B. coli* and *B. proteus* an increase of diamagnetism amounting to 4% was found. This change is independent of the way the cells are killed. Cooling with liquid air had the same effect.

Diamagnetism of Ions

The field of ionic diamagnetism is still in a state of confusion, both as regards the theoretically calculated and experimentally determined values. The theoretical values, due to Pauling, Stoner, Slater, and Angus, do not agree in many cases and often differ widely. The deduction of ionic diamagnetic susceptibilities from experimental measurements gives no better results.

The main methods employed for deriving diamagnetic susceptibilities from experimental measurements are :

(1) *Measurement from halogen acids in aqueous solution with the assumption that* H^+*ion in the free state exhibits zero magnetic susceptibility.*—But as H^+ion in solution has a strong polarizing effect, this may lead to an erroneous result as pointed out by Weiss (*J. Phys.*, 1930, **1**, 185; *Compt. rend.*, 1930, **190**, 95).

(2) *Theoretical division of measured alkali halide susceptibilities.*—Joos (*Z. Physik*, 1923, **19**, 347; 1925, **32**, 835) suggested that the ionic susceptibilities of isoelectronic alkali halide ions may be obtained by simply dividing their molar susceptibilities, as measured in solutions, in the inverse ratio of the square of their atomic number. For, diamagnetic susceptibility, being dependent upon the square of the electronic radius, will be inversely proportional to the square of the atomic number. The method was improved by Brindley (*Phil. Mag.*, 1931, **11**, 786) by replacing the square of the atomic number (Z) by the square of ($Z-S$), where S is the screening effects of electronic shells. This is merely an application of Slater's theoretical method for the experimental derivation of ionic diamagnetism values (*Phys. Rev.*, 1930, **36**, 57).

(3) *Employment of homopolar susceptibility values.*—Weiss (*loc. cit.*) employed a rather arbitrary procedure in deriving cationic and anionic susceptibilities from their corresponding Pascal's atomic values by subtraction or addition of 3 units respectively for every unit of charge on the ion. This is named by him as *constant bond effect* invariant with ionic structure.

Föex (*Compt. rend.*, 1930, **190**, 481) derives ionic susceptibility from that of the corresponding atom as given by Pascal, by multiplying the latter with a proportionality factor given by the ratio between the number of electrons in the outermost level of the ion and of the corresponding atom. For instance, the ionic susceptibility of the halogen ions is given by multiplying the corresponding homopolar values by 8/7.

Miss Trow (*Trans. Farad. Soc.*, 1941, **37**, 476) suggested a relation between the atomic susceptibility of Pascal, and the ionic susceptibility applicable to halogen ions, for instance, Cl^- :

$$\frac{\chi_{Cl}\,(\text{Theor.})}{\chi_{Cl}\,(\text{Expt.})} = \frac{\chi_{Cl^-}\,(\text{Theor.})}{\chi_{Cl^-}\,(\text{Expt.})}$$

The theoretical values were obtained by Slater's method. χ_{Cl} (Expt.) is the Pascal's constant for Cl-atom.

Dividing the measured molar susceptibility of solid alkali halides with isoelectronic ions in the ratio of the square of the crystal radii of the corresponding ions, as given by Pauling or Goldschmidt (*The Nature of the Chemical Bond*, Oxford, 1940) we have calculated the ionic diamagnetism of the halogen, alkali and alkaline earth ions. That is, from

$$\frac{\chi_{M^+}}{\chi_{X^-}} = \frac{(r_{M^+})^2}{(r_{X^-})^2}$$

and knowing χ_{MX}, the values of χ_{M^+} and χ_{X^-} can be readily calculated. The values have been calculated with different halogen or alkali ions as standard. For the alkali and halogen ions the results give quite consistent values and are possibly better than those obtained by any other method, theoretical or practical. These are given in Tables I, II and III. The values for alkaline earth ions are, however, unsatisfactory as is the case with all other methods (Table IV). The values for Li^+ when calculated by additivity relation from the halogen standard becomes negative (*i.e.*, paramagnetic). But calculated from LiH-value by radius ratio method it gives a molar susceptibility of 0·36.

TABLE I

Ionic diamagnetic susceptibilities calculated by crystal radius ratio method, using values for solid alkali halides with isoelectronic ions from Brindley and Hoare's measurements (Proc. Roy. Soc. A., 1935, 152, 342; 1937, 159, 395)

Ion ..	Li^+	Na^+	K^+	Rb^+	Cs^+	F^-	Cl^-	Br^-	I^-
$-\chi_{cryst.} \times 10^6$ ..	0·36*	5·11	13·6	20·61	31·36	10·49	25·2	35·79	51·24

* From LiH

These are represented as primary standards and are indicated by star marks in the following tables.

TABLE II

Diamagnetic susceptibility of halide ions from experimental values of solid alkali halides (Brindley and Hoare, loc. cit.*) from additivity relation using the values of different alkali ions as standard*

Standard	$(-\chi_{cryst} \times 10^6)$			
	F^-	Cl^-	Br^-	I^-
Na^+ (5·11)* ..	10·49*	25·09	35·99	51·89
K^+ (13·60)* ..	10·00	25·20*	35·60	52·10
Rb^+ (20·61)* ..	11·29	25·79	35·79*	51·59
Cs^+ (31·36)* ..	13·14	25·34	35·84	51·24*

TABLE III

Diamagnetic susceptibility of alkali ions (cryst.) using the values of different halogen ions as standard from additivity relation

Standard	$-\chi_{cryst} \times 10^6$				
	Li^+	Na^+	K^+	Rb^+	Cs^+
F^- (10·49)* ..	−0·39	5·11*	13·11	21·41	34·01
Cl^- (25·20)* ..	−2·10	5·00	13·60*	21·20	31·50
Br^- (35·79)* ..	−1·79	5·31	13·41	20·61*	31·41
I^- (51·24)* ..	−1·24	5·76	14·46	20·96	31·36*

The negative values obtained for Li^+ is obviously due to the fact that the lithium halides have crystalline forms quite different from the other alkali halides. Hence, the value deduced by additivity relation becomes unreliable in this case.

The values of the alkaline earth ions, calculated with the halogen ion values as standard and using the experimental values of crystalline alkaline earth halide susceptibility (Brindley and Hoare, *loc. cit.*), are given in Table IV.

TABLE IV

Standard		$-\chi_{cryst} \times 10^6$			
		Mg^{++}	Ca^{++}	Sr^{++}	Ba^{++}
F^- (10·49)*	..	1·72	7·02	13·72	25·62
Cl^- (25 20)*	..	−1·20	4·20	11·10	21·90
Br^- (35·79)*	..	..	−0·18(?)	7·32	17·02
I^- (51·24)*	..	..	6·52	7·52(?)	21·92

The different values for one and the same ion differ widely. The alkaline earth halide measurements are probably not reliable, particularly for the bromides. Besides, the structure of the alkaline earth halide crystals differs from those of alkali halides.

The use of the measured molar susceptibility of magnesium fluoride and oxide with isoelectronic ions, as the standard for calculation, was, therefore, expected to lead to a decided improvement:

$$\chi_{MgF_2} = -22{\cdot}7\times10^{-6} \text{ (Brindley and Hoare, \textit{loc. cit.})}.$$

From this, by radius ratio method using the crystal radii of Mg^{2+} and F^- ions as given by Pauling (0·65 Å and 1·36 Å respectively), the values of $\chi_{Mg^{2+}}$ and χ_{F^-} are obtained as $-2{\cdot}3\times10^{-6}$ and $-10{\cdot}2\times10^{-6}$ respectively. But as magnesium fluoride crystallizes in the rutile structure, the magnesium ion in the crystalline fluoride probably exists under a constraint developing some paramagnetism, thus giving a somewhat lower value for diamagnetic susceptibility. In magnesium oxide, which crystallizes in the symmetrical rock-salt structure, the magnesium ion may be regarded as free from any such constraint. Hence, a measurement on a freshly prepared specimen of magnesium oxide from magnesium carbonate (Merck's G.R. quality) was made in a quartz fibre torsion balance by Dr. A. K. Dutta of the Department of X-ray and Magnetism of this Association, for which the author is thankful to him. The value for χ_{MgO} was found to be $-10{\cdot}17\times10^{-6}$.* This by the radius ratio method ($r_O = 1{\cdot}40$ Å) gave $\chi_{Mg} = -1{\cdot}8\times10^{-6}$. This is, however, lower than that derived from MgF_2, due possibly to the greater polarizability of the binegative oxygen ion. As we are concerned with the alkaline earth halides it is preferable to use the values of $\chi_{Mg} = -2{\cdot}3\times10^{-6}$ and $\chi_F = -10{\cdot}2\times10^{-6}$ for deriving from additivity rule the diamagnetism of other alkaline earth metal ions, as also of halide ions, using Brindley and Hoare's (*loc. cit.*) experimental values for alkaline earth halides in the solid state. The results are given in Table V.

The experimental value for SrI_2 was considered doubtful by Brindley and Hoare. The value for I^- ion with Sr^{++} as standard has, therefore, been excluded in calculating the mean. The values derived are quite satisfactory and show the validity of the additivity rule for the alkaline earth halides, starting with $\chi_{Mg^{++}}$ and χ_{F^-} as standards, deduced from the experimental value of χ_{MgF_2} by the radius ratio method proposed here. The χ-values for the halide ions are somewhat lower than those deduced from the χ-values

* A somewhat higher value of $-10{\cdot}8\times10^{-6}$ was reported by Dr. S. Kumar of the Central Glass and Ceramic Research Institute from measurement by Gouy's method.

TABLE V

Standard	$(-\chi_{cryst} \times 10^6)$			
	Mg^{++}	Ca^{++}	Sr^{++}	Ba^{++}
F^- (10·2)* ..	2·3*	7·6	14·3	26·2
Cl^- (23·45) .. (from $MgCl_2$)	2·3*	7·8	14·6	25·4
	2·3	7·7	14·45	25·8
Standard	F^-	Cl^-	Br^-	I^-
Mg^{++} (2·3)* ..	10·2*	23·45	..	..
Ca^{++} (7·7) ..	10·15	23·50	31·85	50·65
Sr^{++} (14·45) ..	10·12	23·52	32·23	47·8 (?)
Ba^{++} (25·8) ..	10·4	23·25	31·4	49·3
	10·22	23·43	31·83	49·98

of alkali halides. This may obviously be attributed to the difference in the crystal structure of the two types of halides, as also to the increased polarization of the halogen ions by the bipositive alkaline earth metal ions with consequent reduction of the effective radius of the halogen ions. The values for the alkaline earth metal and the halide ions thus show a slightly better agreement with additivity rule than those of the alkali halide ions. The anomalous values of the alkaline earth metal ions, as previously observed, now disappear altogether when the experimental value of an alkaline earth halide (*viz.* MgF_2) is made the starting point of calculation.

In aqueous solution in general, the ionic diamagnetism is about 2-3 per cent higher than for the solid crystals. But here also different investigators give different values for one and the same ion.

A comparison of ionic susceptibility values for halogen, alkali and alkaline earth metal ions, as obtained by different methods, both experimental and theoretical, is made in Table VI. The experimental values, excepting those in column 5, refer to measurements in aqueous solution.

The values for the alkaline earth metal ions show a wide variation, which is not unusual as they are based on the halide ion values of the alkali halides.

In Table V the ionic diamagnetic susceptibilities of alkaline earth halide ions, determined by the radius ratio method using the χ_{MgF_2} value (solid) of Brindley and Hoare (*loc. cit.*), on the other hand, show a remarkable agreement among themselves and provide a definite evidence about the danger of unrestricted application of the additivity rule in deriving ionic diamagnetism.

The uncertainty of ionic diamagnetic susceptibility values may result from many factors, *viz.*:

(1) Purity of the sample (free from ferro- or para-magnetic impurities).
(2) Difference in crystal structure in the case of solids.
(3) Difference in valency of the component ions in the crystal, leading to their polarization.

(4) Variation in concentration in solutions; for there may be hydration of ions and depolymerization of water molecules.

(5) Accuracy of measurements.

TABLE VI

Ionic Diamagnetic Susceptibilities: Experimental and Theoretical
Alkali and Alkaline-Earth Halides

$-\chi \times 10^6$

Ion	1	2	3	4	5	6	7	8	9	10	11
F^- ..	10 5	..	12·1	..	9·4	8·1	16·9	8·1	7·1	11·23	10·49
Cl^- ..	26·5	22 9	18·3	25·3	24·2	29·0	39·5	25·2	22·3	25·36	25·20
Br^- ..	35·4	35·9	30·0	37·1	34·5	54·0	..	39·2	35·9	35·81	35·79
I^- ..	53·6	51·5	47·7	55·4	50·6	80·0	..	58·5	54·1	51·71	51·24
Li^+ ..	0·75	3·0	6·7	−0·1	0·7	0·6	0·7	0·7	0·7	−1·38	0·36
Na^+ ..	5 25	8·5	12·5	5·3	6·1	4·2	5·4	4·1	3·7	5·30	5·11
K^+ ..	14 8	16·6	21 1	15·4	14·6	16·7	17·2	14·1	12·8	13·65	13·6
Rb^+ ..	22·6	23·4	28·2	20·4	22·0	35·0	29·4	25·1	23·5	21·05	20·61
Cs^+ ..	35·4	39·8	44·3	36·6	35·1	55·0	..	38·7	36·4	32·07	31·36
Mg^{++} ..	4·0	7·3	13·6	1·6	4·3	3·2	4·3	3·1	2·8	..	..
Ca^{++} ..	11·6	10·8	18·5	4·5	10·7	13·3	13·1	11·1	10·2	5·93	..
Sr^{++} ..	19·0	20·8	28·5	14·0	18·0	28·0	..	21·0	19·7	13·2	..
Ba^{++} ..	29·9	32·6	41·1	25·3	29·0	46·0	..	32·6	30·9	21·6	..

1. Klemm's method using Slater's theory. *Z. anorg. u. allgem. Chem.*, 1940, **244**, 377; 1941, **246**, 347.
2. Weiss's method from halide acids with cation correction. *Loc. cit.*
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10. Radius ratio method for solid crystals (mean values).
11. Radius ratio method for solid crystals (standard values).

A comprehensive discussion about the sources of error will be found in the *Review of Modern Physics* (1952, **24**, 15) in a paper by Meyer, as well as in the Presidential Address of Mata Prasad in the *Journal of the Indian Chemical Society* (1954, **31**, 181).

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VI. THE LATITUDE EFFECT OF COSMIC RADIATION *

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I. Introduction

Although one would be hesitant to designate any individual cosmic ray discovery as the most significant single advance in the light of the subsequent history of the subject, the statement that the latitude effect constitutes perhaps the most far-reaching of the vast variety of phenomena which have been investigated certainly cannot be gainsaid. Its all-pervading influence is manifested in practically all of the numerous investigations which have provided the information for arriving at what may now be regarded as a rather complete description of the nature and properties of the primary cosmic rays. For, since the earliest observation of the correlation between cosmic ray intensity and geographical position established that the primary cosmic rays were largely, if not entirely, corpuscular rather than electromagnetic, the effect has subsequently been repeatedly invoked in the analysis of experiments which have yielded a fairly precise picture regarding the composition of the incoming particles, their absolute intensities, and their distribution in energy. The solution of even the most perplexing and still only partially-resolved problem of the origin of cosmic rays is likewise governed by the latitude effect, and the currently-accepted hypotheses are indeed based upon the dependence of certain observations upon the geomagnetic co-ordinates.

As a consequence of the fortuitous circumstance that approximately two-thirds of all the energy brought to the earth by cosmic rays is carried by particles that are measurably influenced by the terrestrial magnetic field, study of this subject has assumed a truly international character. Co-operation and collaboration among scientists of many nations have been stimulated on a scale unparalleled in the history of physics owing to the fact that, in view of the existence of the geomagnetic effects, observing stations which are especially suitable for some particular type of experiment are scattered over the globe.

It happens that 90 per cent of the primary cosmic rays which enter the earth's atmosphere vertically at very high latitudes are *field sensitive*, *i.e.*, they would be prevented by the earth's magnetic field from reaching the geomagnetic equator in that direction. The fundamental principles regarding the orbits of electrically-charged particles in the dipole magnetic field of the earth were originally developed by Störmer (1904) in connection with his studies of the aurora borealis. His theory was subsequently extended by Lemaitre and Vallarta (1933) and others to treat the geomagnetic effects of cosmic radiation in an analysis rendered feasible by the recognition of the applicability of Liouville's general dynamical theorem to this problem, as demonstrated by Swann (1933). This implies that if charged particles are distributed isotropically at large distances from the

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earth, the flux of particles of a particular type having a given momentum is the same in all allowed directions throughout the accessible regions of space as it would be in the absence of the magnetic field. Hence, it is not necessary to consider the individual orbits in detail, but only to determine the minimum momentum required for arrival in a given direction at a specific point. Thus, the earth's field acts as a magnetic spectrograph, and in particular, the only direct method available for determination of the distribution in energy of the bulk of the incoming protons, utilizes observations of the vertical intensity at the highest attainable altitudes at different latitudes. Geomagnetic theory defines the corresponding minimum momenta required for arrival,* hence, in view of the aforementioned considerations, the energy spectrum of the field-sensitive primaries can be deduced from the measurements of the intensity near the 'top of the atmosphere'. Analysis of the geomagnetic effects is independent of the composition of the primary cosmic radiation when the cutoffs are expressed in terms of magnetic rigidity, pc/Ze which is, therefore, the most relevant quantity for the discussion of data obtained with instruments that do not discriminate with respect to the nature of the particles counted.

During recent years, considerable evidence has accumulated indicating that the sun is certainly the source of low energy cosmic rays on some occasions (cf. Chakraborty and Chatterjee, 1949; Pomerantz, 1951) and indeed could be the origin of most of the particles at the low energy end of the spectrum (Firor *et al.*, 1954). For theoretical reasons, the upper limit of the magnetic rigidity of solar-produced particles is estimated at 10 Bv, a surmise which appears to be substantiated by the absence of intensity changes near the geomagnetic equator during any of the four recorded occasions upon which large solar-flare events enhanced the cosmic ray intensities as observed at sea-level simultaneously at widely-separated points on the earth (Forbush, *et al.*, 1950). However, the number distribution of primaries having rigidities exceeding 2 Bv appears to follow approximately the same inverse power law up to the highest rigidity (10^{15} Bv) for which data are presently available (Barrett *et al.*, 1952) although a marked departure occurs at the low-energy end of the specturm (Pomerantz, 1950, 1951). It would be somewhat surprising if the magnetic rigidity distribution of particles originating at the sun were precisely the same as for the primaries of higher rigidity emanating from the far reaches of the galaxy. Inasmuch as India lies in the equatorial region where the minimum magnetic rigidity required for entrance in the vertical direction extends from 10 Bv to 15·5 Bv, conditions here are especially suitable † for a detailed comparison of the spectrum of the cosmic rays arriving from these two sources, particularly in view of the availability of excellent facilities and the competent assistance required for such investigations. As a consequence of this circumstance, the author has enjoyed the privilege of conducting an extensive programme of experiments in India utilizing balloon-borne instruments to examine in detail the energy-dependence of various properties of the primary cosmic rays. The results of the 29 flights released at Aligarh, Uttar Pradesh (geomagnetic latitude 18° N.) and Bangalore, Mysore (geomagnetic latitude 3° N.) have already been described (Pomerantz, 1954*a*, *b*, *c*). Primary flux measurements were obtained with the same standardized equipment which had previously been extensively utilized at higher latitudes as far north as 69° N. (*loc. cit.*). Based upon the measurements at 52° N. and 3° N. the

* See Alpher (1950) for an excellent presentation of this subject and references to earlier review articles.

† Actually, certain complications arise from the uncertainty in the contribution of the penumbral region. For a discussion of this matter, see Pomerantz, 1954*a*.

primary magnetic-rigidity integral spectrum averaged over the range of lower limits 2·1 Bv to 15·4 Bv is

$$N(>pc/Ze) = 0{\cdot}68(1+pc/Ze)^{-1{\cdot}2} \qquad \text{(1)}$$

However, the data recorded within the equatorial region require a higher value of the exponent in the differential distribution corresponding to eq. (1) if the usual assumptions underlying this type of determination are valid. This may be indicative of an irregularity in the spectrum at the upper limits of the field-sensitive region for vertical incidence such as is to be expected when the primaries are predominantly of galactic rather than solar origin. The flux of primary helium nuclei was also measured, and, as may be seen in Fig. 1, it was concluded that both protons and alpha particles can be represented by an integral energy distribution of the form:

$$N(>E) = K(1+E)^{-} \qquad \text{(2)}$$

where E is kinetic energy per nucleon; $k = 4000$ and $1{\cdot}5 < E < 15$ Bev for protons; $k = 450$ and $0{\cdot}3 < E < 7$ Bev. per nucleon for alpha particles. Furthermore, the composition of the primary cosmic radiation is not drastically different at $\lambda = 3°$ and $\lambda = 18°$.

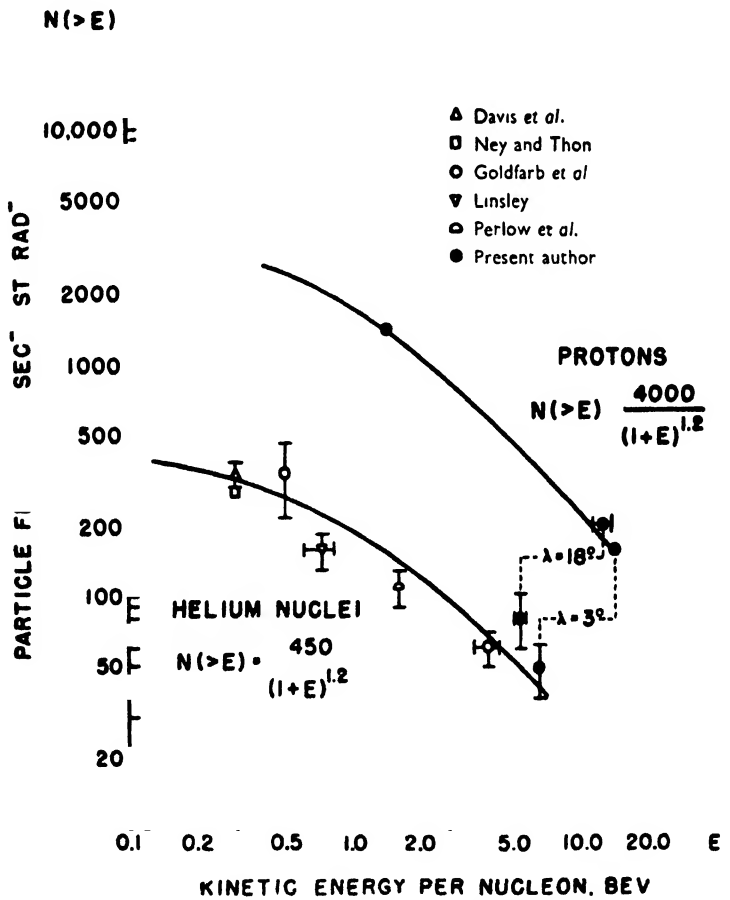

FIG. 1. Dependence of the flux of primary protons and helium nuclei, respectively, upon threshold energy per nucleon. After Pomerantz (1954*b* and *c*).

In view of the fact that the variation of the primary intensity with latitude observed within India was anomalously high as compared with the overall change between 3° and 52°, it is of interest to examine in detail and consolidate all available information regarding the latitude effect at low altitudes. During the course of the pre-flight ground runs of the quadruple-coincidence counter trains, data were recorded which may be compared with similar measurements at higher latitudes. Although it had been planned to conduct observations in the Himalayas up to heights of 14,000 feet for direct comparison with earlier measurements at Mt. Evans, Colorado, (Pomerantz, 1949) circumstances beyond the control of the writer unfortunately precluded accomplishing this mission. However, it is possible by appropriate analysis to deduce the latitude effect at 9,000 feet, where there was a limited period of operation. It is the purpose of the present paper to consider in a critical manner all of the available information regarding the variation of the cosmic ray intensity as a function of latitude in the lower atmosphere.

The latitude effect coefficient, which may be represented by

$$\epsilon = -\frac{\partial N}{N \partial \lambda} \quad \ldots \quad (3)$$

is a quantity which depends upon latitude. However, in view of the existence of the so-called *knee* as demonstrated by the observations to be described in the following section, a satisfactory index for the comparison of the results of different investigators near sea-level may be expressed in terms of the percentage decrease in the measured intensity recorded when the detecting instrument is moved from a high latitude ($\lambda > 40°$) to the geomagnetic equator. Thus, the latitude effect will here be defined by the relationship

$$L = 1 - \frac{N(\lambda_2)}{N(\lambda_1)} \quad \ldots \quad (4)$$

where $N(\lambda_1)$ is the intensity at $\lambda > 40°$, and $N(\lambda_2)$ is the intensity at the geomagnetic equator (or some other specified low latitude).

II. Earlier Observations

The variation of cosmic-ray intensity with latitude was discovered by J. Clay (1928) whose observations during a series of voyages between Java and Genoa showed an equatorial dip in intensity amounting to about 11 per cent. Subsequent verification was provided principally by the very comprehensive world-wide survey of Compton and his associates (1933) which involved about 17 physicists and 69 stations at various latitudes, longitudes, and elevations. An extensive survey at sea-level with an automatically-recording electroscope placed aboard various ships was conducted by Millikan and Neher (1936) whose results are shown in Fig. 2. Although the relative values assigned to the contours of equal cosmic ray intensity or *isocosms* are not necessarily in accord with all of the data reported in the literature, this chart appears to be consistent with most of the recent observations. The most thorough study of the sea-level latitude effect, particularly with respect to changes which may occur during the course of a year, was conducted by Compton and Turner (1937) on the Pacific Ocean between Vancouver, British Columbia and Sidney, New South Wales. As is evident in Fig. 3, their measurements indicated a total latitude effect of 10·3 per cent, of which 7·2 per cent was ascribable to a truly geomagnetic effect. They noted the existence of a seasonal variation which

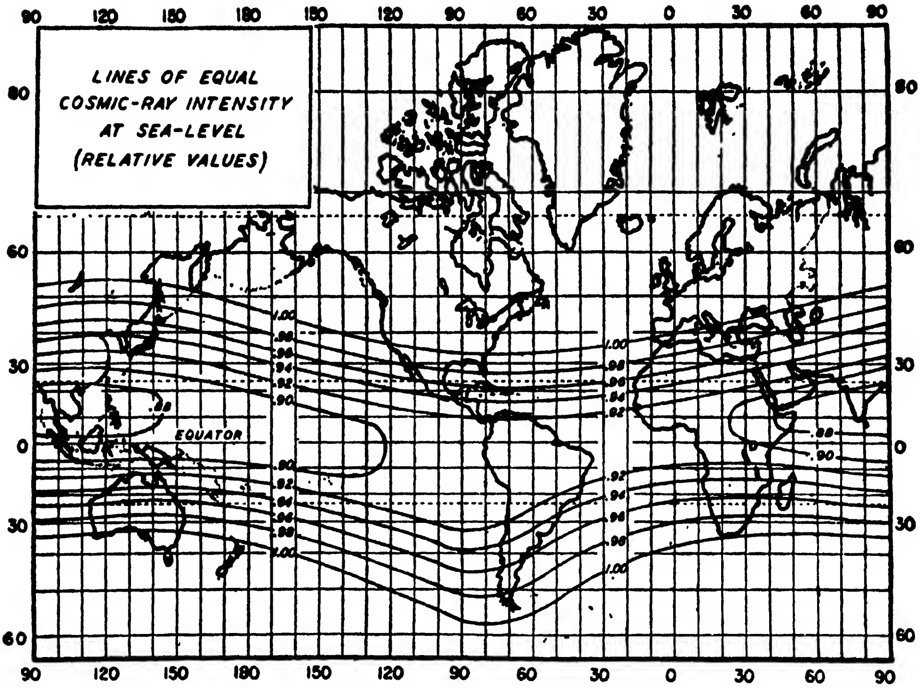

FIG. 2. Lines of equal cosmic-ray intensity (isocosms) at sea-level. The latitude effect, L, varies from about 8 per cent along the 75th meridian to about 12 per cent at 80° E. The longitude effect corresponds to a harmonic term of amplitude 2 per cent. The intensity was measured with an automatically-recording spherical ionization chamber, shielded with the equivalent of 11 cm. of lead. After Millikan and Neher (1936).

correlates with temperature, and which was consequently designated the *external temperature effect.* The fact that the intensity in cold months is higher than that during the warm season was attributed to an atmospheric barrier of unknown nature of whose strength the temperature of the atmosphere is an approximate but not an exact index. Indeed this may actually constitute the first evidence for the instability of one of the components of cosmic radiation. We now know that the observed seasonal variations are a consequence of the spontaneous decay of mesons. Fig. 3 is of interest here because it indicates the extent to which meteorological factors may be expected to introduce disparities among the results of different investigators.

The first latitude-effect measurement with a G-M counter coincidence train was that of Auger and Leprince-Ringuet (1933). They reported a diminution of 16 per cent independent of whether or not a 20 cm. Pb absorber was interposed during a voyage between LeHavre and Buenos Aires. Various observations of this type were subsequently conducted by many investigators. For example, Pickering (1936) measured a 17 per cent latitude effect with 1·6 cm. Pb above the counters, while Johnson and Read (1937) observed values ranging from 12 per cent to 20 per cent in the vertical direction with no interposed absorber.

Among the more recent observations with which the measurements to be reported in the present paper may be compared are those of Morris, Swann, and Taylor (1947), Winckler *et al.* (1950), Walsh and Piccioni (1950), and Law *et al.* (1949). Relevant

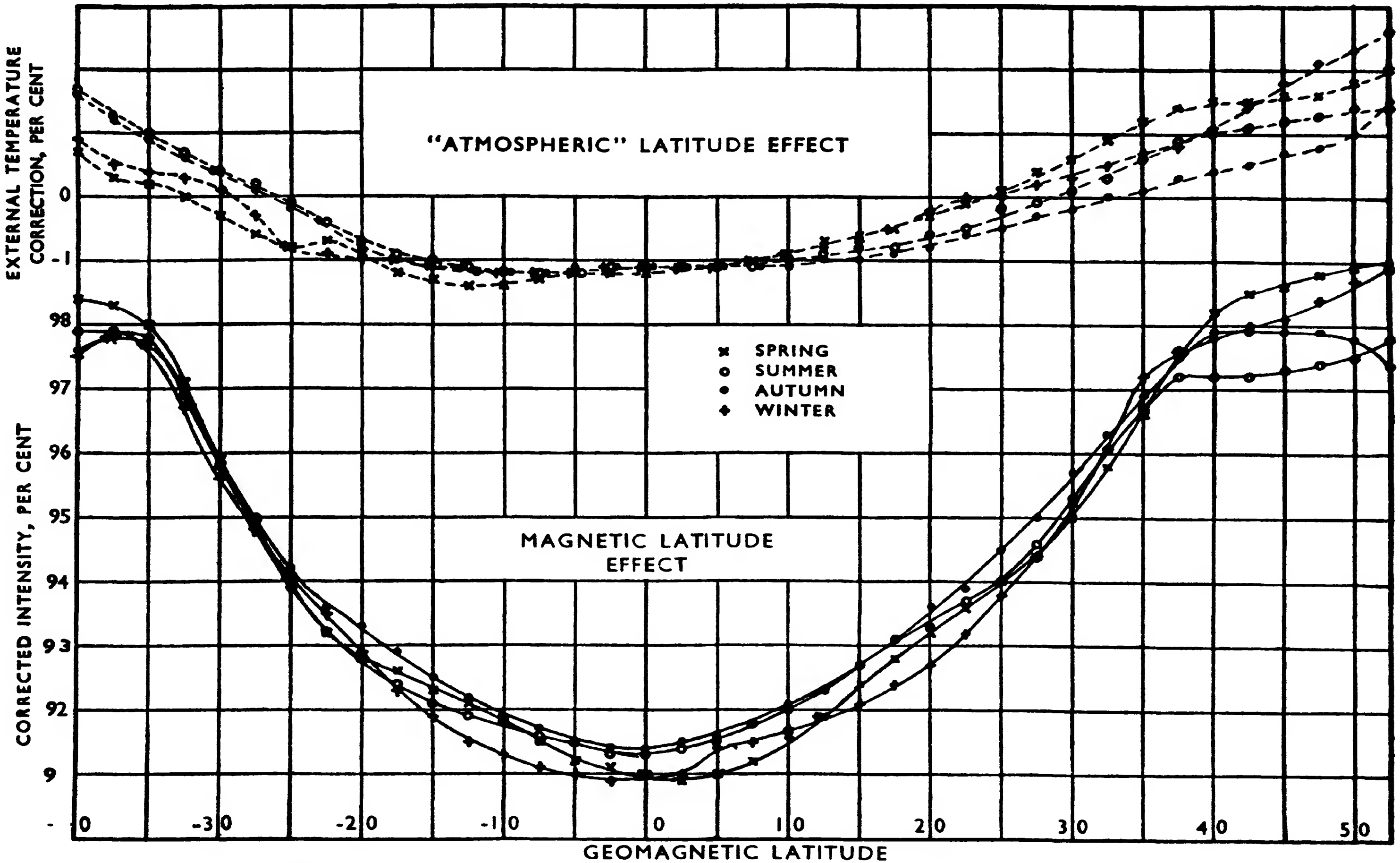

FIG. . The sea-level latitude effect showing the part attributed to the external temperature effect and that ascribed to a truly geomagnetic effect. It is to be noted that the seasonal variations are largely included in the temperature effect. The intensity was recorded with an automatically-recording ionization chamber, shielded with 12 cm. of lead. After Compton and Turner (1937).

measurements at airplane altitudes were obtained by Bhabha *et al.* (1945), Swann and Morris (1947), Schein *et al.* (1947), and Biehl *et al.* (1949). Their results are summarized in Table I. The first experiments indicating the magnitude of the latitude effect at very

TABLE I

Summary of recent latitude-effect determinations

Reference	Atmospheric pressure, mm. of Hg	Absorber thickness, cm. Pb	Terminal Stations		Latitude effect, L, per cent
			λ_1	λ_2	
Morris (1947) ..	760	0, 8, 16	Boston, Mass., 53° N.	Rio de Janeiro, Brazil, 12° S.	5*
Winckler (1950) ..	760	0	Port Hueneme, Calif., 40° N.	Jarvis Island, 0°	14
Law (1950) ..	760	0	Australia, 40° S.	Japan, 0°	13, 20†
Walsh (1950) ..	760 282 220	17‡	Rome, N.Y., 55° N.	Panama, Canal Zone, 21° N.	7 19 25
Bhabha (1945) ..	184	20	Bangalore, Mysore, 3° N.	....	20§
Swann (1947) ..	202 191	15	Ohio, 58° N.	Lima, Peru, 0°	34 25
Schein (1947) ..	191	20	United States, 40° N.	Peru, 0°	29
Biehl (1948) ..	228	0 10 21	Hudson Bay, Canada, 64° N.	Lima, Peru, 0°	37 40 34

* Represents combined data for latitude ranges 15° S.–15° N. and 28° N.–53° N. respectively.
† With wide-angle and narrow angle telescope, respectively.
‡ Approximately 12 cm. Pb above instrument, 5 cm. Pb interposed.
§ Data obtained only at single station, normalized to balloon-flight data Schein *et al.* at 51° assuming 12 per cent sea-level latitude effect.

high altitudes were conducted by Bowen, Millikan, and Neher (1938). Recently, measurements of the primary flux at both high and low latitudes have been obtained by Winckler *et al.* (1950), Van Allen and Singer (1950), and the author (*loc. cit.*).

III. FLUX MEASUREMENTS NEAR SEA-LEVEL AT 18° N.

During the course of the ground runs of the balloon-borne instruments, which have previously been described in considerable detail, (see Pomerantz, 1954*a*, and references

contained therein) extensive data which may be compared with similar measurements at high latitudes were obtained. Table II contains a summary of a series of measurements

TABLE II

Summary of data recorded on the ground at Swarthmore, Pennsylvania, and Aligarh, Uttar Pradesh. All of the uncertainties indicated are statistical standard deviations.

Station	Swarthmore, geomagnetic latitude 52° N.				Aligarh, geomagnetic latitude 18° N.			
Average atmospheric pressure	756 mm. of Hg				745 mm. of Hg			
Absorber overhead	35 g.cm.$^{-2}$ concrete				67 g.cm.$^{-2}$ concrete			
	Instrument number	Total counts	Total time, min.	Counting rate, counts per min.	Instrument number	Total counts	Total time, min.	Counting rate, counts per min.
	1	9595	11500	0·834±0·008	1	3062	4133	0·741±0·013
	2	5865	6919	0·849±0·011	2	5812	8050	0·723±0·010
	3	3333	3864	0·862±0·015	3	5157	6932	0·745±0·012
	4	3910	4568	0·855±0·013	4	2707	3572	0·758±0·015
	5	3645	4258	0·855±0·014	5	3103	4132	0·752±0·014
	6	3296	3907	0·844±0·014	6	8294	11578	0·718±0·008
	7	4471	5465	0·820±0·012	7	1805	2409	0·749±0·017
	8	4925	6001	0·820±0·012	8	2884	3887	0·741±0·013
	9	2023	2413	0·839±0·018	9	3312	4618	0·716±0·012
	10	1604	1894	0·847±0·020	10	3489	4693	0·744±0·013
					11	4271	5839	0·732±0·011
	Totals	42658	50789	0·840±0·004	Totals	43896	59843	0·734±0·004
	Corrected to absorber thickness and atmospheric pressure at Aligarh			0·805±0·004	Latitude effect, $L(52°–18°) = 8·8 \pm 0·6$ per cent.			

at Aligarh and at Swarthmore, respectively, in which the coincidence counter trains were operated with no interposed lead absorber under a concrete roof.

Two corrections are required in order to compare the counting rate at Swarthmore directly with that at Aligarh. The first is necessitated by the fact that at the former location, the laboratory roof is not as thick as at the latter. The second must take into account the small difference in altitude between the two stations.

The material overhead at Aligarh consisted of 67 g. cm.$^{-2}$ of concrete, whereas that at Swarthmore was 35 g. cm.$^{-2}$. The reduction in the Swarthmore counting rate necessary to reconcile the measurement with that in Aligarh, under the thicker ceiling, is determined from absorption measurements at Swarthmore. The relative stopping powers of lead and concrete for mesons which can just penetrate 35 g. cm.$^{-2}$ and 67 g. cm.$^{-2}$ of concrete, respectively is 0·6. Hence, the counting rate at Swarthmore under 35 g. cm.$^{-2}$ of concrete is the same as that under 58 g. cm.$^{-2}$ of lead. Similarly, under 67 g. cm.$^{-2}$ of concrete, the counting rate would be the same as under 112 g. cm.$^{-2}$ of

lead. If it is assumed that the differential absorption produced by the addition of 32 g. cm.$^{-2}$ of concrete (54 g. cm.$^{-2}$ of lead) above the detector is equivalent to that which would result from interposing the same amount of material in the counter train,* the absorption coefficient is $-1{\cdot}32\times10^{-3}$ g.$^{-1}$ cm.^{2} Pb and the attenuation factor which must be applied to the Swarthmore data is $[1{\cdot}00-(1{\cdot}32\times10^{-3})\ (54)] = 0{\cdot}93$.

The altitude correction which must be applied to the Swarthmore data to increase the intensity to that which would have been observed at Aligarh requires knowledge regarding the variation with altitude, over the pressure interval 756 mm. of Hg to 745 mm. of Hg, of the counting rate of the instrument utilized in these experiments under 67 g. cm.$^{-2}$ of concrete. The author has conducted a series of determinations of absolute particle intensity at various altitudes in the lower atmosphere (Pomerantz, 1949) which are in excellent agreement with the observations of Greisen (1942). Although the author's measurements at Swarthmore and Mt. Evans embrace the altitude interval in question, the increment is rather large, and it cannot be assumed that the variation with

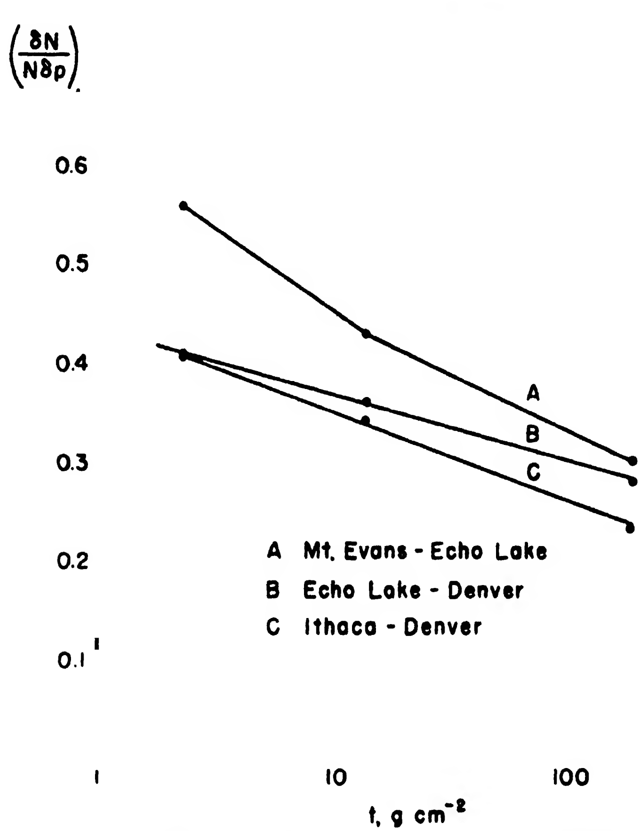

FIG. 4. The quantity $\alpha_t = \left(\frac{\partial N}{N\partial p}\right)_t$ plotted as a function of absorber thickness for three different pressure intervals.

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* Actually, because of the effects of scattering, a superposed absorber does not reduce the intensity quite as much as an equal thickness of the same material placed between the counters. To a first approximation as many particles are scattered out of the train as into it in the latter case, whereas in general material overhead is more efficacious in scattering particles into the solid angle of the telescope. The conditions here are such that this effect may be neglected.

pressure is linear over this region. However, Greisen's measurements at Ithaca, New York and Denver, Colorado provide the desired information. We shall define the enhancement coefficient α_t by the following expression:

$$\alpha_t = \left(\frac{\partial N}{N \partial p}\right)_t \quad \ldots \quad (5)$$

Curve C, Fig. 4, is a plot of the enhancement coefficient as a function of absorber thickness, t, computed from Greisen's data. The value corresponding to 67 g. cm.$^{-2}$ of concrete (112 g. cm.$^{-2}$ Pb) is then multiplied by the difference in pressure between Swarthmore and Aligarh to yield the correction factor $[1+(0{\cdot}25)\,(11)] = 1{\cdot}03$.

Thus, the final corrected counting rate at 25° N., adjusted to correspond to the same absorber thickness and altitude as in the case of the measurements at Aligarh is (0·93) (0·84) (1·03) = 0·805 counts per minute. The latitude effect near sea-level with respect to 18° in India is thus 8·8±0·6 per cent.

IV. Flux Measurements at 9,000 feet

Data obtained at Gulmarg in Kashmir are summarized in Table III. Measurements made with the same experimental arrangements at Mt. Evans and Echo Lake, Colorado, are also listed. Several alternative procedures may be adopted for correcting the data to take into account the differences in elevation and absorber thickness.

Table III

Summary of data recorded at Gulmarg, Kashmir, and Echo Lake and Mt. Evans, Colorado. The measurements obtained at each location with two separate instruments of each type have been combined.

Station	Average atmospheric pressure, mm. of Hg	Instrument	Interposed absorber,* g. cm.$^{-2}$ Pb	Total counts	Total time, minutes	Counting rate, counts per min.	Counting rate reduced to atmospheric pressure at Gulmarg	Observed counting rate at Gulmarg	Latitude effect, L, per cent
Gulmarg, geomagnetic latitude 23° N.	567	A	0·0	9,568	5,935	1·61±0·02			
			47·2	7,507	7,190	1·04±0·01			
			85·0	6,310	6,425	0·98±0·01			
		B	0·0	32,135	11,490	2·80±0·02			
Echo Lake, geomagnetic latitude 49° N.	515	A	0·0	874	365	2·39±0·08	1·91	1·61	15·7
			70·8	711	514	1·38±0·05	1·16	1·01†	12·9
Mt. Evans, geomagnetic latitude 49° N.	453	A	0·0	3,560	1,090	3·27±0·05	1·83	1·61	12·6
			47·2	4,608	2,499	1·84±0·03	1·20	1·04	13·3
			85·0	2,690	1,645	1·64±0·03	1·10	0·98	10·9
		B	0·0	7,479	1,392	5·37±0·06	3·24‡	2·80	13·6

* Not including counter walls.

† By interpolation.

‡ Adjusted on basis of direct calibration at Swarthmore for slight geometrical change.

The altitude variation is again accounted for on the basis of Greisen's measurements, which were considerably more extensive than the author's over the altitude range involved in these considerations. Thus, the atmospheric absorption coefficient, $-\alpha_t$, defined by Eq. (5) with a negative sign is plotted as a function of absorber thickness in Fig. 4 for the two intervals Echo Lake-Denver and Mt. Evans-Echo Lake, respectively. Utilizing Curve B, observations at Echo Lake with 70·8 g. cm.$^{-2}$ of lead can then be reduced to correspond to the altitude of Gulmarg by the relationship

$$N(p_1) = N(p_2)\,[1-\alpha_t(p_1-p_2)] \quad .. \quad .. \quad .. \quad .. \quad (6)$$

where p_1 and p_2 represent the atmospheric pressure at Echo Lake and Gulmarg, respectively. By a linear interpolation of the intensity as a function of lead thickness between 4 cm. of Pb and 7·5 cm. of Pb at Gulmarg, we determine the counting rate with 70·8 g. cm.$^{-2}$ of lead.

Similarly, the counting rates at Echo Lake and Gulmarg with no interposed absorber other than the counter walls may be compared by reducing the Echo Lake value on the basis of Curve B and Eq. (6) with t = 5 g. cm.$^{-2}$.

Alternatively, the counting rates observed with both instruments A and B at Mt. Evans may be reduced to the altitude of Gulmarg by the same general procedure involving Fig. 4. However, the correction is now applied in two steps, first from Mt. Evans to Echo Lake, by means of curve A, and then from Echo Lake to Gulmarg, utilizing curve B. In this manner, the values tabulated in Table III have been determined for the A instrument with zero, 47 and 85 g. cm.$^{-2}$ Pb, and for the B instrument. The latitude effect corresponding to each set of measurements is also listed. The consistency is satisfactory, and the average value is $L(49°-23°) = 13{\cdot}1 \pm 0{\cdot}6$ per cent, the indicated uncertainty representing the standard deviation based upon the distribution of individual determinations, rather than upon the total numbers of counts.

V. Flux Measurements at Higher Altitudes

It is of interest to compare the present determinations of the latitude effect with observations made with the same instruments at higher altitudes, as well as with the results of others. Table IV is based upon our balloon-flight measurements as well as those of Neher's group with both G-M counter trains and ionization chambers.

VI. Discussion

It must, of course, be borne in mind that fluctuations arising from the variation in the altitude of production of mesons may introduce an absolute uncertainty in the latitude effect at sea-level of several per cent; the fluctuations could be somewhat greater for data recorded in aircraft (Swann, 1949), as first pointed out by Kupferberg (1948). The precise net effect upon comparisons of observations made in different parts of the world and in different seasons is extremely difficult to evaluate, although this does not vitiate certain meaningful comparisons.

As is indicated in Table I, various observers have demonstrated that the latitude effect in the lower atmosphere does not vary rapidly with absorber thickness. This is in accord with the present observations, although there appears to be a slightly smaller latitude effect for 18 cm. of Pb than for 4 or 7·5 cm. of Pb in the intermediate region (approximately 300 to 50 mm. of Hg).

TABLE IV

Comparison of latitude-effect determinations at high altitudes in Eastern and Western Hemispheres.

Atmospheric pressure, mm. of Hg	Latitude effect, L, per cent					
	India* $\lambda_2 = 18°$ N.			Peru† $\lambda_2 = 0°$		
	Interposed absorber, cm. Pb					
	4·0	7·5	180	0	10·4	20·8
530	15			15	18	13
400	24	21	23	20	24	23
300	39	39	31	32	33	31
228	43	46	38	37 36§	40 47‖	34
				India‡	$\lambda_2 = 17°$ N.	
200	48	48	38	43		
80	67	64	59	58		
20	77	77	78	74		
0	80	86	85			

* Present author.

† Biehl, Neher and Roesch (1949).

‡ Bowen, Millikan and Neher (1938) and Neher and Pickering (1942) with thin-walled ionization chambers. $\lambda_1 = 51°$.

§ Unshielded ionization chamber.

‖ Ionization chamber with 11 cm. Pb shield.

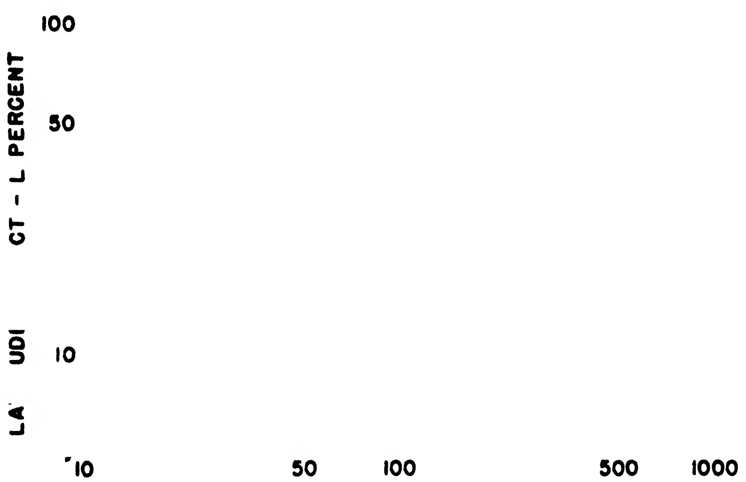

FIG. 5. The latitude effect between geomagnetic latitudes 52° N. and 18° N., L (52°–18°), as a function of altitude on the basis of the present experiments

At lower altitudes, the latitude effect with respect to the geomagnetic equator in Peru is approximately equal to that with reference to 18° N. in India. This would be compatible with the equality of the cutoff rigidity at the two locations which prevails when the eccentricity of the terrestrial dipole is taken into account. However, the trend toward higher values in India as compared with Peru may actually be real.

The relative intensity observed at sea-level is in agreement with that obtained with an ionization chamber by Millikan and Neher (*cf.* Fig. 2). The observations of Compton *et al.* (1933) yielded higher values of the latitude effect in India. From Compton's data for Lahore (743 mm. of Hg, geomagnetic latitude 21° N.) and Chicago (745 mm. of Hg, geomagnetic latitude 53° N.), $L(53° - 21°) = 16{\cdot}9$ per cent. The reason for this discrepancy is not clear. We can also deduce a value corresponding to Gulmarg by making use of Compton's data in the Himalayas. The result at 567 mm. Hg based upon measurements at Lal Tibba and Rohtang La is 20 per cent.

The observed increase of the latitude effect with elevation had originally led to the qualitative prediction that the latitude effect of the vertical radiation alone would be larger than that of the radiation detected by an omnidirectional detector. As a matter of fact, an analysis involving the Gross transformation reveals that the latitude effect measured with a narrow-angle counter telescope would be about 1·5 times that observed with an ionization chamber (Johnson, 1938). Although the azimuthal asymmetry does not introduce a serious error, the neglect of the instability of the mesons and other factors obviously now invalidate this type of argument. For it appears to be an experimental fact that ionization chambers yield the same latitude effect as vertical coincidence-counter trains throughout most of the atmosphere.

Our value for the latitude effect at sea-level is in good agreement with that of Winckler *et al.* (1950) with $\lambda_2 = 18°$, as it should be on the basis of the approximately equal threshold rigidities. However, the corresponding value of the primary flux is higher in India (*loc. cit.*).

In conclusion, the author wishes to express his gratitude to the National Geographic Society for its continuing support in sponsoring the India Expedition, and to Dr. Lyman J. Briggs, Chairman of the Research Committee, for his constant encouragement. It is a pleasure also to thank Aligarh Muslim University, with which the author was privileged to be affiliated during the year 1952-53 under the Fulbright programme, and the Vice-Chancellor, Dr. Zakir Hussain, for the kind hospitality extended to us. The facilities of the Physics Department, which participated actively in the project, were made available through the helpful co-operation of Professor P. S. Gill. The author is happy to thank the Indian Institute of Science, Bangalore, and especially Professor R. S. Krishnan, for making available both facilities and assistance. The active participation particularly of S. P. Agarwal, H. S. Hans, R. M. Mathur, and J. Prakash, Government of India Research scholars, as well of G. W. McClure, T. J. Tidd and A. E. Viele, and many others too numerous to mention individually contributed materially to the successful completion of this programme. Finally, the author is grateful to Dr. W. F. G. Swann, Director of the Bartol Research Foundation, for his constant interest and encouragement.

Summary

The impact of the latitude effect upon the present state of our knowledge regarding the primary cosmic radiation has been very great. An extensive programme of experiments utilizing balloon-borne instruments has been conducted in India. In the present

paper, the latitude effect at low altitudes is determined, and the balloon-flight results are compared from this point of view with other related data. The latitude effect near sea-level with respect to 18° N. in India is $8{\cdot}8 \pm 0{\cdot}6$ per cent, and at an altitude corresponding to 567 mm. of Hg, at 23° N., it is $13{\cdot}1 \pm 0{\cdot}6$ per cent. The latitude effect does not vary rapidly with interposed absorber thickness. Vertical G-M counter trains yield approximately the same latitude effect as ionization chambers throughout most of the atmosphere.

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VII. THE PROGRESS OF ELECTROENCEPHALOGRAPHY

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(*Received for publication on October 15, 1954*)

I. Introduction

In response to the request of the Chairman of the Committee it is a pleasure for me to write something about the history and present status of Electroencephalography (EEG) for the coming issue of the *Transactions of the Bose Institute* that will be dedicated to Dr. D. M. Bose, its Director, on the occasion of his seventieth birthday. This account will be partly reminiscent and descriptive and partly scientific.

Dr. Bose showed much interest in this new field when it was introduced. The writer, as the Sir J. C. Bose Research Fellow of the Calcutta University in biophysics soon after the Fellowship was established, received every co-operation from Dr. D. M. Bose, his colleagues and the authorities of the University in establishing the first electroencephalographic laboratory in India. The laboratory was located in a small room in the Bose Institute next to the auditorium that in years past was the scene of many brilliant experimental demonstrations by the famed physicist and botanist, Sir Jagadish. A single channel brain-wave machine was built in 1939 by one Mr. Roy for the laboratory according to our specifications. It was a simple home-made affair with a push-pull preamplifier, power amplifier and ink-writer, but it did the work. Its frequency response was, as tested by cathode ray oscillograph, as far as the writer can recall, linear between one and thirty or forty cycles. Its noise level was about 5 microvolts and it did record human brain waves within the sub-audio frequency range and up to several hundred microvolts without significant distortion. Records were taken on normal people including twins, deaf and dumb children and some clinical cases (8). Preliminary reports were presented before the Indian Science Congress in Madras in 1940 (6, 7) and in Banaras in 1941. This simple EEG machine may look primitive compared to modern 4 to 8 channel machines, six or seven of which are used in India today, including two in Calcutta.

Circumstances made it necessary for the writer to come back to America in 1941 and abandon all his plans to return to India. The situation about EEG was rapidly changing here. Since the discovery of the existence of spontaneous and rhythmic human brain potentials in 1929 by Berger of Germany the field of EEG had been on the defensive for quite a long time (14). Berger was ridiculed and his work suffered from lack of recognition. Some reasons for this have been mentioned elsewhere (5). Dr. E. D. Adrian, Nobel Laureate from Cambridge University, famed for delineating the electrical response characteristics of single nerve fibres and for other original contributions, repeated, in co-operation with his co-workers, Berger's experiments on themselves and were the first to announce to a doubting scientific world in 1934 that Berger was essentially correct (2). Five laboratories in America, already carrying on animal electro-physiological studies, immediately entered this field—Harvard, Brown, Chicago, and Iowa Universities, and

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Tuxedo Park. The writer recalls the excitement in Iowa when the first human brain potential graphs rolled off the machine in 1935 and 1936 (4). Prior to this, electrophysiological experiments on peripheral nerves and brains of animals were also being performed at Washington University, Rockefeller Institute and a few other institutions. The results of experiments on the central nervous system of animals offered clues to the interpretation of the fundamental characteristics of the potentials of the human brain. It was not until Dr. William Lennox, President of International League Against Epilepsy and Dr. Frederick Gibbs, both of Harvard, recorded some dramatic electrical changes from the brains of epileptics in 1935 that it was realized that EEG was not simply a research tool in the physiological laboratory but a very important diagnostic aid to clinicians concerned with disorders of the brain (29). This realization resulted in the expansion of the work in America from the five original laboratories to hundreds in the past nineteen years. Large hospitals and universities now have EEG departments. This expansion has been to a certain extent paralleled in other countries.

The American EEG Society was formed in 1946. The writer has the privilege of being a member of the charter group. The membership, composed of those holding doctorate degrees, medical or non-medical and who are actively engaged in EEG work, has increased markedly. It includes neurologists, neurosurgeons, psychiatrists, physiologists, neuroanatomists, psychologists, general practitioners, biophysicists, biochemists and electrical engineers. Specifications for machines with high gain and discrimination ratio have been standardized. The International Federation of EEG Societies was organized in London in 1947. The quarterly *International Journal of EEG and Clinica Neurophysiology* was launched in February, 1949. Apparatus, clinical material, and particularly basic neurophysiological research, in addition to reviews of pertinent books, references to literature, and abstracts of papers presented in American and foreign EEG Societies receive due consideration in the *Journal*. The Board of Qualification for certifying candidates for the practice of clinical EEG has been functioning for the last few years under the direction of the American EEG Society. This Board has been both praised and criticized but its thoroughness and fairness never questioned. The major concern, or shall we say headache, of the members of the Membership and Nominating Committees has been to pass upon candidates for admission to the Society and to suggest next year's officers. Fortunately this concern was not the writer's until recently. Up till now the officers have been nominated and then elected chiefly for their experience and skill in research and not primarily for their administrative ability. Annual meetings of the American EEG Society list papers every year of fundamental neurophysiological interest and those pertaining to clinical electroencephalography. In addition, special subjects for half-day symposia are covered in these meetings.

Besides the American EEG Society there are four regional EEG groups in America—Eastern, Western, Southern and Central EEG Societies, the writer being closely connected with the last. Each holds one or two scientific meetings during the year at different centres. The overlapping membership of these five Societies must be about six-hundred. There are EEG Societies in England, France, Germany, Italy, Denmark, Holland, Belgium, Sweden, Switzerland, Spain, Japan, and some countries of South America. Several hundred thousand records would be a conservative estimate of EEGs taken all over the world. In Ann Arbor EEG laboratory alone over seventeen thousand records, which are being microfilmed now, have been taken with 3 eight channel and previous three and six channel machines. Twenty-five per cent of these are localizing records each of which comprises 300 to 500 sheets of 13″×8″ paper. In addition there are

Cathode Ray Oscillographic records and electrocorticographic records taken during temporal lobectomy or other brain operations performed for the relief of medically uncontrolled psychomotor seizures or other conditions of the brain.

In August of 1953, the Third International Congress of EEG was held in Boston attended by several hundred delegates. Twenty-four foreign countries were represented including Australia, Japan, South Africa and many countries of Europe and South America. No one was sent from India. Professor E. D. Adrian of England, was the Honorary President, and Dr. H. H. Jasper, the President of the International Federation of EEG Societies which sponsored the Congress. Professor Alexander Forbes, well-known neurophysiologist of Harvard, was President of the Congress. Professor Forbes's welcoming message was: 'It is indeed a privilege to welcome guests from so many distant lands, assembled to discuss new developments in neurophysiology. Nothing in all the realm of science comes closer to the things that mean most in human life than the study of the nervous system and how it makes us what we are. This Congress offers a great challenge to further progress' (60). Among many foreign workers were Bremer from Brussels, Buchthal from Denmark, Gastaut from France, Moruzzi from Italy, Penfield from Canada, Tönnis and Jung from Germany, and Walter from England. Among many American workers were Bishop, Brazier, Davis, Gerard, Gibbs, Magoun, Marshall, McCulloch, O'Leary, Walker, and Wiener. In addition to eighty scientific papers, six symposia were presented, namely, recent developments in EEG techniques (frequency analyser, auto-correlator, toposcope), the physiological basis of EEG including study of D.C. brain potentials, evaluation of activation of EEG, inter-relationships between cortex and subcortical structures, EEG in infancy and childhood, characteristics and significance of seizure discharges. Unrehearsed, on-the-spot, interpretation of electroencephalograms projected on the screen was done without prior clinical information before approximately 400 people by a panel of eight delegates, three from Europe and five from America. The experience was quite stimulating to the writer as to other panel members. These pictures later made their rounds in Europe.

One of the most unusual exhibits at the Congress was Walter's Toposcope. In its elaborate model it uses frequency and phase-lock devices and projects simultaneously on twenty-two miniature cathode ray tubes the alternating voltages of the spontaneous or activated rhythm from twenty-two areas of the brain in their varying intensities and phases. Differences in experimental situation such as the exposure of the eyes to flicker stimulus, startling sound or psychological reactions will produce striking multiplicity of areal changes in the parameters of the visible toposcopic patterns, which can be photographed on a moving film. Toposcopic changes have not yet been statistically evaluated in order to justify definitive conclusions. This work certainly represents an advance since it is known that the phase difference of alternating potentials of different areas of the brain cannot be properly detected on a standard EEG machine giving voltage-time records. The toposcope was exhibited by Dr. Walter and Mr. Shipton, a few days prior to the Congress, at the University of Michigan during their lecture. Another demonstration was concerned with using transistor circuits in remote stimulation. Stimulus signals were transmitted from a remote outside transmitter to a small receiving device permanently embedded in the brain of animals causing behaviour changes in these animals under different stimulus conditions in their unanaesthetized state.

Toward the close of the Congress, Professor Adrian, who was originally responsible for authenticating the EEG phenomenon in human beings for the doubting scientific world, confessed that nineteen years ago he could not visualize the progress that has since

been made in EEG and that he had been incorrect in estimating its scope. He indicated certain lines along which its bright future lay.

II.

In spite of the phenomenal growth of EEG as an art and science as suggested by the previous account and as further exemplified by many thousands of listings in EEG bibliography over the last two decades, it must be admitted that more is known about the correlation of brain potentials with clinical syndromes than about brain potentials themselves (23, 32, 38, 39, 57, 59). Hypotheses about these potentials in terms of physical constants and cerebral physiology and morphology are only in the process of formulation on the basis of pharmacological, biochemical, stimulation and ablation experiments (3, 16, 18, 21, 31, 63, 64). For lack of space they will not be described here. In spite of divergent views and speculations there is varying measure of agreement regarding the following concepts:—

(1) Brain potentials are probably cell or membrane potentials and not aggregates of axon potentials although characteristics of net-works and conditions governing the axon potentials may modify the rate, voltage and distribution of the cell potentials when they are summed (19, 20, 21, 35).

(2) Brain waves depend upon brain metabolism. That is, ionic changes inside single cells and ionic exchanges between the cells and their environment through their semipermeable membrane are functions of cell metabolism (35). Critical changes in metabolism cause changes in frequencies and amplitudes of brain potentials. Brain rhythm disappears in an irreversible manner in absence of oxygen for a short time. Enzymes, potassium, and other chemicals play definite rôles.

(3) The phenomenon of autorhythmicity of nerve cell aggregates no matter where they are located—in the medulla of a gold fish or in the abdominal ganglia of cray-fish—is universal (1, 21, 38, 55). These cell aggregates can act independently of the central pacemaker or regulatory centres. Isolated and insulated cortex can beat spontaneously without the aid of pacemakers if its circulation is kept intact (27, 33, 42).

(4) Intralaminar nuclei of the thalamus (not the latero-ventral nuclei) and medial reticular formation of the brain stem exercise influence over the potential rhythm of the entire brain through diffuse projection systems which are not all anatomically delineated (24, 25, 37, 40, 41, 46, 47, 48, 49, 50, 51). They are cerebral pacemakers or regulatory centres. The amygdala is likely to be another one of these (28).

Penfield's concept of centrencephalon (52, 53) involving the upper brain stem, thalamus, hypothalamus and reticular formations as the highest level of integration (and of ? consciousness) being connected to and acting upon both cerebral hemispheres is slowly gaining ground. Although there is resistance to the acceptance of the notion of a fixed centre of consciousness being in this region (43), it is felt on the basis of electrophysiological and clinical evidence that this region is somehow intimately connected with it.

(5) Reverberating circuits within cell aggregates and between certain parts of thalamus and cerebral cortex are possible; indeed they are present (17, 21, 26). But brain potentials do not always depend upon thalamo-cortical reverberation (see Section 3). Thus there is the inevitability of both local and total action (5).

(6) Ten per second alpha rhythm is more of a complex phenomenon than it was originally thought. However much tied-up with the striate area it represents subcortical influence. It may be present in other isolated cell-aggregates too.

(7) EEG reflects only part but not certainly the entire electrodynamics of the brain. Many potential changes, normal or abnormal, are masked or not recorded in EEG.

(8) By way of analogy it has been proposed that the nervous activity is somewhat similar to what is found in a relaxation oscillator which shows the type of oscillation differing from that commonly discussed in physics which is dependent upon inertia reacting with elasticity. An example of a relaxation oscillator may be given: 'A neon lamp with a parallel condenser in series with a resistance and electromotive force will discharge at regular intervals, namely when the potential difference across the condenser reaches a certain critical value' (34). Similarly it may be conceived that the potential of each nerve cell, which is evidently caused by its intrinsic continuous metabolic activity, builds up to a critical value and only then does it discharge like a condenser; the cell is replenished quickly and discharges again giving the alternating beat something like the flashing neon lamp.

(9) The function of scanning in projection and association areas of the brain for picking up and reflecting the spatial pattern of activity projected from the receptor has been attributed to alpha rhythms (63). This idea has been intriguing to all workers but it has neither been developed nor rejected.

(10) The accepted notion of nerve impulse transmission over restricted neural pathways and of fixed cerebral centres of localization should probably be supplemented by the notion of more or less fluid patterns of mass electrical activity in the brain capable of functioning at different levels of integration in order to handle endogenous and exogenous signals for adequate response. However no satisfactory theory has been worked out along that line. Results of many learning and post-ablation relearning experiments on primates and subprimates are found by some to be in certain respects inconsistent with rigid ideas of cerebral localization (43). There are new concepts of servomechanism or feed-back system propounded by Pitts and McCulloch and Wiener and space co-ordinate system by Lashley (43, 54, 65). These concepts formed about cerebral activity to explain perception, conceptual thinking, memory, learning and behaviour, although not comprehensive, represent attempts that are the result neither of pure armchair speculation nor of microscopic anatomy. EEG, electronics, neurophysiology, neuroanatomy, mathematics and clinical knowledge each makes its contribution, waiting for further clarification of the fundamental issues.

A question is raised from time to time in informal gatherings by some inquisitive scientific minds of the East and West, namely, is it worthwhile to use brain potential study to evaluate the rationale of ancient psychophysiological practices of Hindu *sadhana*. Although some studies have been done no definite answer is forthcoming.

III.

This last section will deal briefly with applied EEG—with only one practical clinical application of brain-wave research, namely, the pre-operative localization of brain tumors. Neurologists and neurosurgeons may rely heavily on the focal EEG findings in addition to other findings before recommending brain surgery. Being an absolutely non-traumatic diagnostic procedure EEG has chronological priority over other radical diagnostic methods employed by them and involving certain measure of risk and morbidity, such as arteriography, pneumoencephalography or ventriculography. Although neurosurgeons prefer the visual representation of a tumor as offered by these X-ray contrast studies to EEG evidence, in some medical centres they are anxious to order an EEG especially in

absence of focal clinical signs, and later check its results against those of other studies before brain surgery. Obviously they would not welcome the frustrating and almost disastrous experience of opening a patient's head and not finding a tumor. If the patient shows some vague history of a cerebral condition and no focal clinical and X-ray findings but on the other hand shows a strong EEG focus the neurosurgeon will in these centres invariably revaluate the condition of the patient or wait for further developments. And this in spite of the fact that an EEG focus does not always indicate a surgical lesion. Although EEG has been extensively used to aid in the diagnosis of epilepsy and other central nervous system disorders the complaint is sometimes heard that it has given little help to neurosurgeons. Apart from the possibility of refractoriness of some tumors in showing EEG signs, this difficulty is primarily due to the fault of the EEG technique arising from inadequate coverage of the scalp with electrodes, short sampling time, poor electrode combinations (arrays) and EEG interpretation. This situation has been improving in the last few years.

Brain tumors conduct pathological potentials but do not produce them. It is the gray matter of the cortex that lies contiguous to the tumor and that suffers from pressure, circulatory disturbance, ischemia or edema due to the presence of a tumor which ceases to produce normal alpha (8·5 to 12·5 cycles per second; 5 to 100 microvolts) or beta waves (13 to 30 cycles per second, 25 or 30 microvolts) and gives rise instead to focal slow delta (0·5 to 4 per second) or theta waves (4·5 to 7·5 per second) of complex forms. Interpretation consists in comparing these waves from the areas of one hemisphere with the normal waves from the corresponding areas of the other hemisphere, thus giving the location of the tumor. The interpretation is not as simple as that but the essence of interpretation is comparison. The second and third focal signs of tumor are: exclusive focal spikes occurring in only one to two per cent of tumor cases, and focal hypersynchronous alphas. EEG has sometimes spotted a slow growing brain tumor 2 to 4 years before it was revealed by other diagnostic methods. In our experience with over 4,000 localizing studies very rarely has there been a strong clinical cerebral focus of one type or another without some sort of an EEG focus even though the interpretation of the focus may have been missed in some cases (11). Occasions are not rare when EEG has directed attention to a focal cerebral condition and precipitated action in the clinical management of the case (Fig. 1).

The focal delta or theta waves near a tumor may be considered to be physically due to greater summation and temporal dispersion of normal beats or due to slower beats of the affected brain tissue. No adequate information on this point is available. Interpretation of pathological waves may be very difficult at times even when the best techniques are used. One of the difficulties is due to the confusion between true focal delta or theta waves and such waves as are conducted to and picked up from a distant area on the scalp. To dispel this confusion and to find the true tumor area it has been customary to try to reverse the focal delta or theta wave 180° by putting the area or areas that are showing these waves on the opposite poles (grids) of two channels of a push-pull amplifier (Walter's original technique). That area which shows the 180° reversal is considered the focal area. But it has been pointed out elsewhere that the focal area established by this reverse polarity technique may not always be the tumor area (11), the reason being that because of conduction to a distant area by preferential nerve pathways such waves can be reversed 180° in that distant area. The phase reversal system is, however, important.

Details of EEG recording have been described elsewhere and will not be repeated (9, 10, 11, 12). Essentially the technique consists in attaching 12 to 24 electrodes made of

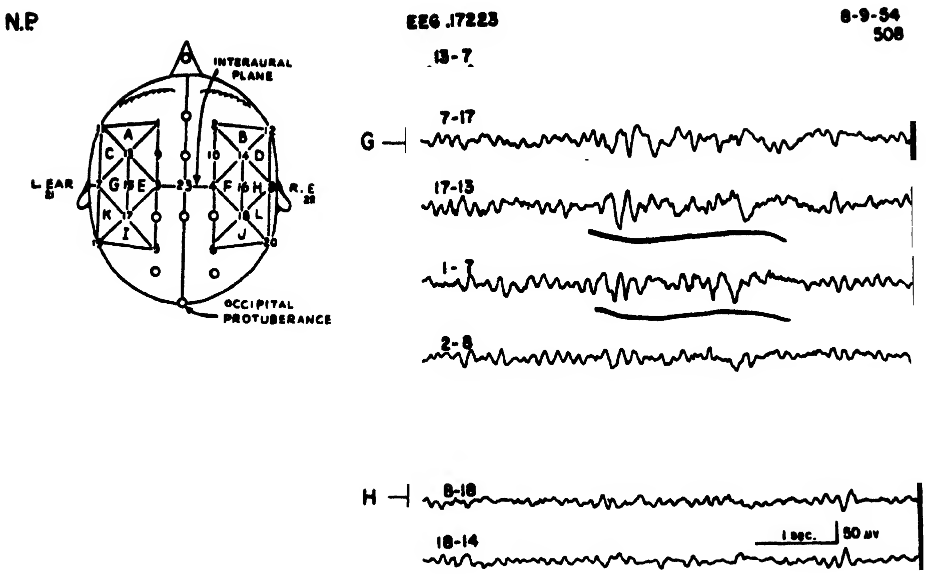

FIG. 1. Shows a short section from a localizing EEG done on a 21-year old patient. She had suffered from grand mal convulsions in early childhood, but had been free of attacks for 10 years. However, she has continued to have attacks during which she is unable to say words. Recent history reveals frontal headache, nausea and vomiting, weight loss of 20 lbs. and several convulsions before admission. Neurological examination negative except for nystagmus to left and ataxia. Initially a cerebral tumor was not suspected. Father had died of a brain tumor.

Triangle G in the left hemisphere (underlined strips 1, 2, 3) shows 50 to 125 microvolt focal abnormal mixed bursts of 5 to 7 p.s. (theta) and single 3 p.s. (delta) waves from the left interaural temporal and lateral parietal regions. Corresponding triangle H in the right hemisphere (underlined strips 6, 7, 8) shows relatively normal alpha waves. Strip 4 on the left compared to strip 5 on the right also shows abnormal focal waves. After an elaborate study of 2½ hours the EEG report was sent to the neurologist indicating that the patient had a focal lesion in the left temporo-parietal sector with anterior extension. First choice was a tumor. EEG led to further diagnostic investigation. Two localizing radio-isotope studies with I^{131} were negative. Lumbar puncture revealed relatively high cerebro-spinal fluid pressure of 190 mm. of water. Contrast X-rays studies of the ventricle with injected air showed shift of the ventricular system to the right and were interpreted as showing a space-occupying lesion in the left parieto-temporal area.

At craniotomy sub-total removal of a large orange-size left temporo-parieto-occipital cystic malignant tumor (glioblastoma multiforme) was accomplished by the brain surgeon. Postoperatively patient's condition was good without any neurological deficit. (Time and microvolt calibration on lower right corner.)

small silver discs or solder pellets with collodion, bentonite or plastic holders to symmetrical positions of the scalp overlying important areas of the brain, connecting these electrodes to the EEG machine and recording the potential difference between scalp electrode and ear ground, or between scalp and scalp electrodes in various combinations. It takes one to three hours depending upon the type of work-up.

TABLE I

Pre-operative electroencephalographic localization of supratentorial brain tumors

Correct localization * to quadrant and/or lobe.	Lateralization *.	Equivocal.	Neg. or False.	Total.
287	24	21	35	367
311 (combined)				
84·7%		5·7%	9·6%	100%

* In cases of deep tumors these categories indicate depth, midline location and/or lateralizing emphasis rather than the structure involved.

Brain tumors have been localized accurately in different laboratories with varying success—50% to 90% (22, 23, 30, 32, 36, 57, 61, 62, 64, 66, 67). Table I including counts of previous and recent tumors shows that our over-all accuracy of pre-operative EEG localization and/or lateralization of supratentorial brain tumors including deep cerebral tumors has been 84·7% (12). This figure is close to the figure reported for ventriculography. When some of the deep tumors in parachiasmatic regions, in III and lateral ventricles are excluded the over-all accuracy rises to 91·1%. If only deep tumors are estimated not including olfactory groove meningiomas and sphenoid ridge meningiomas the accuracy of localization drops to 44%. One of the reasons for failures of localization in these deep tumors (and they include pituitary tumors and other parachiasmatic lesions) is that apparently there are no direct corticopetal fibres from them to relay their disturbed potentials to the cortex or they do not press against the inferior surface of the overlying cortex. Failures of localization in these and other tumors are also due to the character and the rate of the growth of the tumor producing very minimal or markedly diffuse change in the brain. Frontal, temporal, parietal, occipital tumors and olfactory groove and sphenoid ridge meningiomas are amenable to localization. On the basis of elaborate EEG work-up and inspection of nature and distribution of abnormal signs the following information can often be obtained pre-operatively. EEG differentials are briefly summarized here, exceptions not mentioned.

(1) Frontal (focal 1 to 4 per second delta waves) *versus* parietal parasagittal tumors (mostly focal theta waves) (11).

(2) Superficial cerebral (focal 1 to 4 per second deltas) *versus* deep cerebral tumors (bifrontal, bitemporal and/or some shifting deltas and thetas between two hemispheres) (11).

(3) Superficial frontal (focal deltas) *versus* posterior fossa tumors (bilateral and shifting deltas, thetas and/or alpha bursts in widest distribution plus antero-posterior parasagittal variability and often satistical unihemispherical emphasis of bursts) (10).

(4) Discrete *versus* infiltrating tumors (much electrical spread and interareal variability of the delta and theta bursts in addition to strong focus in the latter group) (11).

(5) Tumors (focal deltas or thetas) *versus* focal 'degenerative' condition (in some cases focal positive, negative, diphasic or triangular waves, focal spikes and/or spike-and-waves) (11). No differential EEG information can be gathered about different types of malignant tumors nor about tumors *versus* brain abcesses, subdural hematoma and other focal lesions.

Although EEG literature contains references to posterior fossa (subtentorial) tumors, such tumors were previously considered not amenable to EEG localization (15, 44, 56, 58). Tentative EEG criteria for the localization of these tumors have been recently proposed (10). To date seventy-five cases have been studied. The criteria (see above)

and the detailed findings will not be reported here. On the basis of these it was possible in two-thirds of the cases of posterior fossa tumors to state in advance of operation that there was no superficial cerebral tumor and a deep tumor as in the posterior fossa was likely. Lateralization of lateralized posterior fossa tumors showed better than a chance score. Posterior fossa EEG localization is, however, not as definitive as cerebral localization. Parachiasmatic, anterior or posterior III ventricle tumors cannot yet be differentiated from posterior fossa tumors on the basis of EEG alone. Much more work remains to be done concerning localization of deep tumors. Clinical, EEG, X-ray and other laboratory findings should always be integrated before any surgeon decides to open a patient's head in an attempt to cure a focal disease.

Conclusion

A short account of the history of EEG from obscurity and ridicule to its phenomenal expansion over the last twenty years has been given including that of the first EEG laboratory in India. Some current hypotheses and conjectures about the basic nature of brain potentials are set forth. The research value of EEG for the exploration of known and unknown laws of the living brain and mind has been mentioned. Some data relative to the application of EEG to the pre-operative localization of over 400 verified brain tumors are submitted.

As an addendum it may be stated that for proper diagnosis and treatment of all types of central nervous system disorders in India not only EEG machines but competent EEG interpreters, neurologists and brain surgeons, of whom there are but very few in India, are sorely needed. This matter was called to the attention of the provincial Government in 1950.

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VIII. SOCIETY AND CULTURE

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Introduction

The social behaviour of individuals is determined by two major forces, (*a*) the innate tendencies inherent in all men and women, and (*b*) the effect of external surroundings on them. The external surroundings are geographical, economic, political and social. The history of a people also leaves its impress on the social, political and economic environment. The inherent tendencies are based on the urge to avoid death, to mate with the opposite sex and to feel one's personality in society. This last is often referred to as ego-instinct, as the realization of one's personality involves making one's attitudes, tendencies and aims felt in society through their successful assertion. The other two urges are generally referred to as the instinct of self-preservation and the sex-instinct. The earlier writers assumed instinctive behaviour to be sharply defined behaviour, as is found to a limited extent among birds, insects and lower mammals. In man, even the early infantile behaviour pattern is far more indefinite, except in the matter of some complex reflexes. It has been shown that many so-called instinctive behaviours are really caused by 'conditioning', *i.e.*, by association and repetition under favourable conditions. In man the needs of daily life and the requirements of society lead to repetition again and again of an immense number of actions, accompanied by certain emotional attitudes. In lower animals, the geographical environment and the necessity of food and self-defence largely determine behaviour. Since climate changes very slowly compared to animal life, and, excluding man, other animals cannot deliberately upset the balance of animal and vegetable life in their surrounding, their physical types and patterns of behaviour also change very slowly, *i.e.*, remain more or less fixed over long periods. In the case of early man, the position was similar. But once he learnt to build shelters and to work together to collect food and later on to grow food, social conditioning became increasingly important. In the collecting stage, behaviour was still very simple and stereotyped, of necessity, as the time of men and women was fully occupied in food quest and self preservation. With more plentiful supply of food in the food-growing stage, men and women (hereafter referred to as men only) had more time to think and observe. Even in the collecting stage, it is the women, who moved about less and had more opportunities of remaining quiet and observant, who are believed to have made the epoch-making discovery that seeds, roots and shoots can sprout again when put in earth and can give more food.

Observations of the kind noted which led to the discovery of agriculture are not made by all and sundry. Some human beings have a more sensitive brain and some are less socially conditioned and are able to observe deviations from the normal. It is also evident that new discoveries and inventions can be made only on the basis of existing facts and observable conditions. A more sensitive brain can enable the mind of the possessor to integrate observations better than others. But the factual basis must be present. Thus the Eskimo people have shown great inventiveness within the limits of their available material, and in the direction of helping maritime hunting and fishing with the aid of

traps and harpoons; but they have not invented making of nets, as fibres are lacking. Nor have they invented agriculture, metallurgy or weaving. The cultural level at which they live does not permit such steps to be taken in their arctic surrounding. If a man with the gifts of Newton or Rabindranath Tagore had been born among these people a century ago, the scientifically minded one would have discovered perhaps a better way of judging distances travelled by boats at sea, than his brother Eskimos had known before, and the poetic one made some simple and primitive songs about the dangers as well as beauties of the Arctic region, of Eskimo fishing and hunting and the exploits of Eskimo heroes. He might have even invented a new dance. The laws of mechanics would certainly not have been formulated by the one, nor the unrivalled rhyme and rhythm of Tagore, his dance dramas and short stories and novels revealing deep understanding of human nature and its workings in Bengalee upper middle class society been produced by the other.

Again, although inventions and creations of art are thus determined by the basic environment, and we need also a man of genius, as we term the more sensitive minds, there is a third important factor. While a man of genius can co-ordinate facts where these are available for integration, it is generally found that there are a number of alternative such sets, and only one or a few such are thus co-ordinated by the inventor. Others are left out. This selection itself is not fortuitous, although to the casual observer it may have that appearance. It is determined by environmental bias which includes social trend.

Primeval palaeolithic man decorated his caves with extremely life-like and vigorous pictures of the animals he hunted. He has left us no such portraits of contemporary human beings. Obviously the ancient artist had a choice in the matter of the subject to be portrayed—of animals, as well as men and women, including the woman he had as his mate. In actual practice, the artistic pictures were of animals and were the result of the major subject of importance in that age—the quest of food. The human figures are crude and inartistic and are incidental to the food quest. There is little doubt that magical beliefs about attracting or killing animals played an important part in originating these drawings. The artist had, however, his freedom within limits and a theory of mere magical drawing would not explain the artistic merits of the cave paintings. The general trend of feeling of other ancient men, not only about the quest of food, but also of the vigour and movement of the hunted animal, settled the direction in which the artistic expression of the man of genius took place within the given setting. The paintings of animals, hunted and of actual hunts, by the lowly Bushman of South Africa are justly famed for their excellence. Here also it is the animals hunted that are well drawn. In our own country, the Singangarh cave paintings of Madhya Pradesh reveal a similar characteristic. The hunted animal is well drawn. The human figures are conventionally indicated. This common feature is evidently the result of a common strong social need of all three groups so far apart in space and time—namely, of food to be obtained by hunting certain animals.

In a far more advanced age, magnificent sculpturing of the human face developed in Egypt. Here the basic force was the belief that after death the soul comes back to seek its place of rest. The body of the dead did not perish, when abandoned, in the dry sand of the Egyptian desert. It was naturally preserved. The idea of corporeal immortality, that probably arose in consequence among the early simple folk of Egypt, received a set-back when the cadaver decomposed in its grave chamber which the later and more 'civilized' Egyptians devised for the repose of the 'immortal' body. But the belief had

been established, and attempts to keep the body as it was at the time of death led to the rise of mummification. An image of the deceased was made and left in the chamber to help the soul to get back into the right resting place, or, as some scholars think, to act as a lasting substitute for the perishable body. The social impulse was therefore to make life-like images. The artist as the man of genius saw that statues do not live by merely making exact copies of the living. He added that something else which is his art. That is why statues of the 'king and queen' now in the British Museum, or of the 'Scribe' resting in the Louvre seem to live, as you look at them. In the ultimate analysis, it is the clinging of man to life and its wherewithals—to continue it here (food quest and economy), and the urge to carry it on after life here is ended (belief in immortality and attempts to secure it for the body), which inspired palaeolithic European man, comparatively modern African and Indian tribals, and Neolithic and civilized Egyptians as well.

In a later age this impulse to live hereafter in comfort assumed the shape of religious observance to earn merit. In the middle ages in Italy when the religious forces were strong and the church was a great patron of Art, paintings of the Madonna, of incidents in the life of Christ and of some of his followers who were martyred furnished the outlet for the creative activity of men of genius like Raphael, Leonardo de Vinci and others. Kings and nobles, as patrons of Art, and their women folk also, figured in such paintings. Paintings illustrating the life of craftsmen and merchants appear in Western Europe only after the emergence of the master-craftsmen-cum-merchant to position in society and politics. In our country, the famous paintings of Ajanta and neighbouring Buddhist caves of the early centuries of the Christian era illustrate mainly the life of Bodhisatva and the Lord Buddha and, in that context, incidents of royal courts and royal life. For Gautama Buddha was a prince of Sakyas and his hearers included kings and nobles. His actual disciples after his own life-time included the most illustrious emperor of that period in the world, Asoka, son of Bindusara Maurya.

Artistic expression through literature belongs to a much more advanced and complex culture. To understand its main springs it is necessary to realize how the greater sensitiveness of the minds of gifted individuals reacts to the complex social environment. As we have noted earlier, the behaviour of people in society and also in isolation depends on their early training or conditioning as it is termed. Not only are their explicit responses, *i.e.*, outward behaviour, but also the implicit response, which we term emotion and thought, is moulded by such experience. The nature of emotion precludes too much moulding; but it can be linked practically to any stimulus by conditioning. In a famous series of experiments, Pavlov showed how by conditioning, a dog could be made to wag its tail joyfully on receiving a painful electric shock. The emotional association with stimuli in man is also capable of such distorted conditioning. Social inequalities with their consequent frustration and embittering of the under dog, especially if he is gifted, will produce such abnormal linkage of emotion with tendencies towards behaviour. In advanced societies, the conditioning is too strong to lead even a sensitive mind to react violently by breaking social taboos to the extent desired by him. Hence such trends find expression in creation of stories with such violent wish-fulfilment themes. At a much more primitive level, these develop into tribal myths; in higher society they create literature. The stories of clash between mother's brother and sister's son and of incest between tabooed relatives in Trobriand Islands, where mother-right with some mixture of father-right prevails, are examples of the former. The stories with sex-love as themes written by D. H. Lawrence exemplify the latter.

In man as in other animals the attention is attracted by movement and change in the outer environment. Anything that occurs again and again in the same fashion is practically not consciously observed. Any response to it is organized into the habit-system of behaviour as opposed to deliberate action. These are of course always present as the background of responses to new stimuli. Hence the genius with a sensitive mind will have his attention attracted to the behaviour of that social group or class and to that series of social activity which has the element of newness compared to the background of routine performance. At any period in the history of a people, those who are enslaved or dominated and made to do what their masters desire, reveal very little novelty in their response, except when they revolt. The slavery may be physical or operate through economic, political or social bondage. Hence it is the ruling class among such people who can show the necessary variability that can attract the attention of the literary artist. There is another point to be noted. The artist must have leisure and time to observe. In a society where the lower and enslaved strata are in too great misery to have such opportunity, no creative literary artist can arise at that level. It can give birth occasionally only to militant rebels like Spartacus. The members of the ruling group will be too much conditioned to produce a genius who will see eye to eye with such rebels and create a tale sympathetically portraying them. The creative artist, even if he partly breaks the conditioning,—and the extent to which he can do so is the measure of his mental sensitiveness, *i.e.*, genius—will be limited by his social upbringing and environment. It is only when the people of the oppressed strata have had opportunities to assert themselves at least with partial success and thus break the conditioning to some extent that creative artists will arise who will portray such upheavals in their literary expressions. It is also due to this property of the human brain—to respond consciously to new stimuli which requires to be organized with previous experience—that we may ascribe the flowering of works of genius in times of stress and change. It should, however, be remembered that social forces operate through social contact and conditioning. Hence a new set-up takes a certain amount of time to make itself felt. In the earlier periods of history, before prevalence of mass education and widespread use of the printing press, such delay led to a definitely large lag between the period of maximum change and the resulting production of creative art, science and literature. In those earlier days literary activity was as a matter of course very limited, since only those who could read and write and had facility with the pen possessed the necessary minimum equipment.

We may examine a bit of the history of English literature in the light of these conclusions. We know that England before the Normans was divided into a number of principalities although on some occasions, temporary unity was attained. William the Conqueror set up a centralized kingdom under a single ruler; but under his successors, for a long time, real power was divided between king and nobles, and lordly prelates. In a feudal society without centralized rule, as among the Saxons, or with a loose central bond as among the earlier Norman lords, each nobleman lives his own life with his followers and underlings whose activities revolve round him as the hub. Literary production in these circumstances can be only in the nature of a monologue, a narrative ballad or tale. The earlier 'Tales of Beowulf' was thus composed to regale Saxon thanes. Such literature describes glories of ancestors of the lord, real or mythical, or idealized heroes of the same type.

English had ceased to be the language of literature with the Norman conquest which imposed a foreign rule and tongue on England. It was only after several centuries that English again became the language of literature. The practical loss of dominions in

France besides association of the gentry, the merchants, the yeomen and peasantry in the struggles between king and noble, king and church, and between England and France gradually led to the emergence of the tongue of these people in literature. For they wanted to hear these narratives, wherein their own folk had also some part. The common people outside the burghs had of course their common life, not in isolation like the lord. Hence besides the ballad they had a rude but social form of literature, crude dramas centering around the Saxon hero Robin Hood and his archers. Robin was a national hero, a champion of the poor and he robbed greedy prelates and lords to help the indigent folk. The nobility, on the other hand, had no secular drama written for them but had only lyric or epic ballads. When a centralized rule is set up and feudal lords lose their importance and isolation, they form a social group with close ties of social behaviour. Here the literary portrayal of action-narratives will require a form in which several persons can with advantage have their say in common conversation. In the Saxon period the occasional setting up of central rule did not produce such literature for nobles as very few persons outside monasteries were then literate. Excluding the earlier period when English was not the court language we may say that it was only under the Tudors that a stable and powerful central Government was set up. The earlier literature of this epoch came from men of gentle birth—Spenser, Surrey, Sidney. It was largely lyrical in quality, in keeping with the stress on the individual, which remained as the social heritage from the earlier isolation and self-centred life of the feudal noble inside his walled-in burgh. A new social class had, however, come into prominence, the merchants and the more prosperous craftsmen.

At the end of the fourteenth century, the peasants had risen in the country against the unjust poll tax on the poor. The towns had also joined, as the small merchants and apprentices and craftsmen were aggrieved against ecclesiastical lords and nobles. Half the land belonged to the church. The priests in office were immoral and dishonest, and had disillusioned the common folk by their conduct. The English Bible had been translated and it helped to build up dislike of Papal prelates. At one period, about three times the revenue of the king of England was drained away from the country by absentee foreign priests. The nobles were also oppressive and had numerous rights of manor. The peasant rebels wanted abolition of villeinage and to commute manorial rights for a small rent on land. The nobles sided with the priests and crushed the revolt. It is of interest to note that the king, Richard II, promised the rebels in a conference to abolish villeinage and signed a charter although the promise was not subsequently kept and the charter was revoked. But it is stated that after obtaining the promise of this reform the leaders of the rebels went further. They wanted abolition of all differences of rank and of big landownership. It is alleged that when this demand was made, the negotiations ended in a scuffle in which Wat Tyler was killed. The rising subsided rapidly thereafter. It seems as if the extreme demands, for which the social and economic conditions were not ripe, had alienated many allies of the rebels.

Although the revolt was crushed, the spirit of it persisted. Among yeomen, among merchants, the English Bible was read and hatred of Papal priests and their demands continued. Isolated from the broader demands of the peasantry, the discontent of this small class led to abortive terrorist plots and weak outbursts under the fifth Henry whose foreign war and victories had dazzled his other opponents. Under Henry VII the position was different. Villeinage had disappeared through economic causes. The suicidal War of Roses had reduced the importance of the nobles through death and partial impoverishment. The king, Henry VII, by his treaties with Burgundy, Holland and

Scandinavia had largely promoted commerce. The discovery of America gave foreign trade a further impulse. The small gentry and the merchants were socially allied and rapidly rose into importance as wealthy business men. The desire to read the English Bible (religious impulse) and the need to study about commodities which came through trade and about processes of manufacture of such stuff elsewhere, so necessary for profit, led these people and their imitators among ambitious craftsmen to send their sons to schools and the universities. As a result, there grew up a class not yet the rival of the nobles but quite influential and educated. The conditions were ripe for the production of a new type of literary portrayal of society. Owing to the patriotic fervour that prevailed among all classes under Henry VIII and Elizabeth the social stimulus was to portray the historic triumphs of England. The rude model of plays about national heroes, was there, ready-made in the common folk plays about Robin Hood. The impact of the Graeco-Roman literature that took place as a result of the exodus of the intelligentsia from Greece to Italy following the conquest of Constantinople by Turks had given a powerful bias in this direction for all such production. The study of Latin and Greek among the rising social class and its allies, and the translation of Graeco-Roman dramas and other literature into English tipped the balance of literary form entirely in favour of poetic drama. In less than a century, half a dozen first rate dramatists including Ben Jonson, Shakespeare, and Marlowe and two dozen fairly meritorious dramatists produced their works in this small island. The two other considerable kingdoms, France and Spain, where centralized monarchy had developed, also produced in this period brilliant works of drama. Italy, through which Renaissance had reached these lands, and Germany were not organized in centralized monarchies of this type and did not produce any dramas worth the name either during this epoch or even a century later. To return to the Renaissance drama in England, we note that in form the earlier literary work was modelled largely on the Graeco-Roman tragedies. The influence of the indigenous folk dramas, however, made itself felt, by freeing the form to a great extent of classical trammels. The bulk of the playwrights was drawn from the common people. Marlowe's father was a shoemaker; Ben Jonson was brought up by his step-father who was a brick-layer, and the poet was brought back from Cambridge to wield the trowel. Only he ran away to be a soldier. Shakespeare, however, came from a higher class, of the merchants. He followed also this profession, having a share in his theatre and also in other money-making concerns. The Bard retired quite early in life, in affluent circumstances in the country.

The most powerful feeling that permeated the economically and politically effective classes in his time was that of patriotism—of the feeling of unity as Englishmen. The distinction of Saxon and Norman had disappeared. The foreign domination of the Pope and his satellite clergy had been ended. The civil war which had torn England for several generations had given way to a united national stand. In his historical dramas Shakespeare satisfied this feeling of united England which would not fall any longer at the feet of a conqueror, as it had done earlier when its rulers had fought each other. He portrayed also the struggles against the absolute rule of the king in his drama on John, and the later history of the rulers, in their internecine warfare, their foreign triumphs and their weaknesses. Shakespeare has not spared the ruling class in their follies or baseness, even as he has portrayed their courage and nobility. He has displayed a similar insight into the character of ruling groups in other lands in his tragedies and comedies. Not only has he portrayed their quality as statesmen or traitors, fighters or cowards, but he has given us some unparalleled scenes of tender love, and passion, of jealousy, and of

barbarity towards women. Shakespeare does not preach any message but living figures on his stage display the ruling class as they are in many lands and times, and leaves the spectators to judge them in their own light. His bias in favour of the landed gentry is, however, apparent in the only drama about common folk he wrote—*The Merry Wives of Windsor*.

But the peasants and early merchants who had also fought for their rights, do not belong to this gallery. With all their faults and mistakes they can inspire drama in a democratic age. They did not, however, figure in the vast concourse of people that Shakespeare created. The reason was definite. Shakespeare could not, with his socio-economic ideals, feel inspired by the peasant leaders who led the revolt that shook England under the second Richard. They were illiterate and ill organized; had committed excesses and had made demands which though beyond their times would have meant loss of wealth not only to the nobility but to the merchant-cum-gentry. The dreams of the latter of retiring on the gains of commerce and manufacture, on a country estate would have gone up in smoke if the peasant revolt had truly succeeded. As it is, these leaders of the Revolt failed; they had dared beyond their capacity. Tyler did not become a national hero like Robin Hood, as economic class consciousness was not organized and clear-cut like the earlier well-defined division between the subjugated Saxons and ruling Normans. Hence even Ben Jonson or Marlowe who were of what in a modern age is termed proletarian origin (not strictly so) did not seek to portray him. There was no social demand, explicit or implicit, for such portrayal. There was, however, among ordinary merchants and craftsmen, a contempt for those rich business men who sought to ape the nobility. The greed and meanness of traders and the debasing influence of the pursuit of wealth was also felt. The extreme Puritanism of one section was also disliked. All these are portrayed in satirical dramas and comedies by Ben Jonson and others. Shakespeare's social conditioning and outlook made him avoid this aspect of English life in his dramas. There were other subjects, in English history, its society, and outside, numerous enough to absorb even the immensity of his genius. It would be absurd to call Shakespeare a class supporter on account of such avoidance. It would, however, be equally wrong to deny the effects of his social environment in this respect.

The ancient historical and modern literature of India also reveal the influence of social environment. The early Rigvedic hymns reverberate with calls to battle, rejoicings over victory and curses against enemies. They reveal a period of war and strife. It is only in the later hymns of tenth *mandala*, when greater attention could be paid to other aspects of life that we come across the hymn for marriage and of funeral. There are in the Rigveda also stories of gods and heroes and of their exploits, such as we expect in a democratic community of a group of related villages knit together under a common chieftain. Dramatic works developed much later, when royal courts were well established, with the king as the central figure and his nobles moving in relation to him. The dramas deal mainly with royal heroes, and semi-divine royal figures.

Modern literature had a different source. The provincial languages developed from the spoken tongue of the people, in contact with the more ancient heritage. The clash with orthodox Brahmanism makes itself felt in some of these earlier works. One well-known example is the *Sunya Purana* in early Bengali language. The social suppression experienced by the lowest caste groups led them, in this work, to identify the Muslim invaders with deities avenging their wrongs.

We may now go back to Palaeolithic man again to consider another aspect of man's culture—his scientific creations. As noted before, food was the major problem in the

Old Stone Age and the social stimulus was perforce in the direction of improving its supply. The tools employed by the early Palaeolithic men were very crude, and to judge from the condition of modern primitive hunters with much better weapons of chase, the food collection in these ancient families must have been very poor. The much greater improvement in these implements in the Mousterian, Aurignacian and Magdalenian period accompanied by a favourable climate must have resulted in a more adequate food supply. We know also from our study of primitive tribes that a better food supply leads to more organized social units. With regard to these ancient men we do not possess such direct evidence. But a study of the Cave Art and Arts Mobilier that flourished in this epoch of advanced means of food gathering, has led prehistorians to conclude that the concurrent and successive changes in style and technique of the paintings over fairly wide areas in France and Spain are due to greater social contact among the settlements and specialization of occupation. We can therefore say that better organized societies had developed in this epoch. In that hoary antiquity, scientific progress was mainly in the direction of directed manual skill to make more effective tools. The social need stimulated it. The results of such achievement in its turn integrated society to a greater extent. The erroneous conclusions drawn from observations and beliefs and the ritual resulting therefrom which we know as magic also played a large part in such ancient cultures and were mixed up with correct scientific observations on that humble plane. Even now primitive hunters set traps to catch game skilfully utilizing various mechanical principles in a practical fashion. But at the same time, they utter incantations and perform rituals to ensure success.

Certain important discoveries were made in the epoch following this period. The growing of plant food and the herding of animals resulted from the scientific observations rendered possible by less hard conditions of life, and in areas which furnished a suitable environment for these observations. The change-over from food gathering to food growing led to a far better organized social unit—the agricultural village. The co-operation needed for a steady food supply which in the hunting settlements must have led as among Australians and the Esquimaux to the development of community-sharing of larger game was extended also to the processes of agriculture where the able-bodied individuals had to work together to clear the primeval forest and grow the crops. This helped sharing of experience, and since the men lived in an equalitarian community, promoted pooling of scientific observations. The data available about modern primitive agriculturists like Khasis of Assam or Mundas of Chotanagpur and the records of ancient tribal folk leave no doubt about such a picture of ancient life in the New Stone Age. In our very ancient traditions preserved in the hymns of the Rigveda when society had entered the metal age, the evidence of democracy and equality is apparent. The same family could have a hymn-maker who functioned as a sacred chief of the settlement, as also other members who were craftsmen and common workers. The effect of this large-scale pooling of intellectual and material resources is apparent in the exceptionally large number and variety of scientific inventions that were made in this and the immediately succeeding period. Domestication of practically every kind of cereals and fruit plants, and most of the animals even now used by man occurred in this era. The wheel and its employment in transport, pottery and various machines, the construction of the arch in buildings and the solar calendar came into existence in this epoch. Weaving was invented and a little later metallurgy. The social need of preserving and handing down such a vast body of accumulating knowledge led to the growth and perfection of pictographic writing. Mathematics among rude hunters was limited by social requirement to counting

on fingers and addition and subtraction within such limits. There was no necessity of more advanced arithmetic. In the agricultural communities there was need of much greater knowledge of arithmetic and of surface geometry. The needs of settled irrigated cultivation again, promoted observation of seasons and position of constellations and planets to determine the same. A certain amount of transport by rivers and across coastal seas also developed, making it necessary to make accurate observation of stars and their positions in different parts of the year, and in different areas. In consequence the growth of astronomy and it must be said its magical excresence, astrology, occurred in this socio-economic set-up. In our own country also there were such maritime people in the Sindhu area. In the Rigveda we read of mariners in distress at sea, helped by the Nasatyas, a pair of twin deities who are traditionally recorded as outsiders, admitted later to the Vedic and Smriti pantheon. The knowledge of astronomy, that reached India and was also developed here in that early period, was very limited. The fusion of culture that took place in the millenium before the birth of Buddha, however, left Indian society with a powerful merchant community who traded overseas. The records of the times of the Mauryas, of the Satavahanas and other rulers, and reports of early Chinese travellers furnish adequate evidence of it. For long journeys across the ocean to Java, Sumatra, Egypt and elsewhere, there was necessity of accurate determination of the longitude and latitude at sea. The mathematical knowledge which was then available had been suitable for less complex problems. It became necessary to develop a new mathematical tool. The large educated intellectual class which had grown up in India of those days in a tradition of free thought under good centralized administration helped, in this socio-economic setting, to produce the needed tool. Great advances were made in trigonometry and algebra, and finally Arya Bhatta and his successors, notably Brahmagupta, developed a mathematical technique to determine the instantaneous daily motion of planets which is the forerunner of Differential Calculus, to enable them to make the necessary astronomical calculations. Varaha Mihira in his work *Panchasiddhantika* is acknowledged to have further developed the formula. Indian society and the Indian states were not, however, essentially maritime. Hence a comprehensive systematization of and advance on the ancient mathematical discoveries were not made here.

The beginnings of calculus in this country did not go further forward. The social changes that were leading to greater stringency in the matter of food, of occupation, had started earlier. But due to lack of general education and quick transport and the comparative freedom of thought of the twice-born intelligentsia the effects of such changes were felt after the lapse of some time. In any case, the social stimulus that led Indian mathematicians in the fifth and sixth century A.D. to develop the technique of the calculus, lacked sustaining force. The fishermen caste and seagoing sailors were socially impure. Their captains had no place in policies of State or society. Neither the common cultivator and craftsmen nor the intelligentsia nor the rulers depended on maritime trade for their essential welfare. Hence the force that called forth research in this field of mathematics was limited. It was eventually restricted to determination of exact time of eclipses and connected matter linked to astrology. With greater self-sufficiency and segregation of villages, the impulse became even weaker. Also, the Indian sailors had no social stimulus to build up a powerful navy attached to the Indian mainland. Hence with rise of maritime power among more democratic people, the seagoing ventures of Indians eventually dwindled to insignificance and their needs called forth no further research work from Indian scientists except for a late systematization by Bhaskaracharya in the Vijayanagara kingdom which had maritime connections. Scientific research for

advancement of knowledge passed into the hands of Muslim savants under the liberal Abbaside caliphs and their unorthodox Barmecide ministers.

The problem of navigation became important in Europe with the rise of the Venetian and other Italian mercantile community. The scientific knowledge of the ancient world carried forward one step by the Universities of Baghdad and Cordova had reached the Italians. The socio-economic stimulus received from the needs of the politically important merchant princes led to scientific studies of problems of navigation. The introduction of gunpowder into Europe from Asia and its use in cannon had made knowledge of ballistics and mechanics important in warfare. The political condition of Italy, France, England and Spain made it essential for these to study mechanical science and navigation problems carefully. We find that these were the principal scientific subjects studied in the Universities of these periods. Religious bigotry in Spain, however, throttled critical examination of facts and theories, as these tended to refute religious dogmas. Hence no first rate discovery in science was made in Spain. In Italy in the 17th century the merchant princes protected the scientists in their own interest. So it was possible for Galileo and Leonardo da Vinci to carry out their researches. Even so, in Italy Bruno was burnt at the stake and Galileo was persecuted to martyrdom in his old age when his practical contributions had already been made, and his theoretical views were considered by the princely merchants as inconvenient expressions of heretic opinion. Scientific progress was smothered by religion in Italy thereafter. It is not an accidental coincidence that the telescope was invented in Holland and Italy about the same time. The same socio-economic forces were in operation to stimulate research for an instrument to observe the position of stars to determine longitude at sea and to detect enemy vessels before they could sight the observers. Galileo indeed says so frankly in his report on his telescope. In Holland, large scale maritime trade with Spain and the West Indies was the basis of national prosperity. Also the merchant burghers were mostly Protestant and free from the religious tyranny that ruled in Spain. They needed improved weapons and machines to keep their freedom. We find that a large number of mechanical inventions were made in Holland in the 16th and 17th centuries. England had up to the 15th century no navy worth the name. It was some time after the discovery of America that English naval power grew up. It became important when the merchant-cum-gentry rose to power under the early Stuarts and Cromwell and continued to be so later under the restoration because of its importance in national welfare and to the people in power. The sea-captains in England joined the ranks of the ruling class and came from the common folk as well as the merchants and the gentry. The seamen were socially by no means outcasts. Hence the needs of seagoing persons and vessels were sought to be met by society by various means, one of which was by teaching and research through the Universities. Mechanics and Astronomy were the major scientific subjects in which Professorships were endowed. The reason will be even more obvious when it is stated that in the course of three decades, 'between 1691 and 1721, England alone lost five naval squadrons' because of inability to determine longitude at sea. The making of good clocks, of telescopes, the furthering of mathematical studies of planets, of circular motion and pendulum oscillation, that is to say, practical and theoretical researches in connected fields were widely stimulated. Galileo, Huyghens and Newton are a few of the great scientists of Italy, Holland and England who collaborated indirectly by their contributions in elucidating the problem. It was the great genius of Newton, again, which faced with the lack of adequate mathematical tools to attack problems of planetary motion, developed the elements of Differential Calculus in England, as Arya Bhatta, his pupils and successors

had done earlier in our country. The social need for further research in these directions was very urgent. Hence the development of the calculus by mathematicians went for ward vigorously in Western Europe. Manual skill and closeness of observation are associated with crafts. Feudal warriors and prelates despised working with the hand. Hence even when some of them came across scientifically valuable observations, records were not kept by them or encouraged. A similar attitude of the Egyptian scribes prevented the progress of science in that early civilization. Improvements in technical methods and observations that must have been made by craftsmen in that country were ignored by the scribes. In Greece also, the employment of slaves in all craft work made any progress in experimental science impossible. The only subject which was tolerated was medicine, because of the need of curing ailments. Outside it the particular science in which useful contribution was made, was geometry, based on earlier work of people who had contact with fields and areas. As members of a ruling class averse to manual occupation, the Greek thinkers produced some brilliant speculative hypothesis on the basis of observations made in other civilizations like that of Babylon and Sumer. They had to be logical to convince their equals; but they failed to contribute anything to experimental sciences like physics, chemistry or biology. In our own country also, the caste system with its contempt for manual occupation led to similar limited scientific advances. Thus, a correct theory of propagation of sound was formulated, but details could not be worked out. The Muslims of Baghdad might have been expected, as being more equalitarian, to develop Greek and Hindu science much further on the experimental side. Unfortunately in that great Muslim State the craftsmen although organized in guilds had mostly the status of slaves. Hence here also the basic data for progress in experimental science were lacking to the savants. It was only when the Western European merchant and skilled craftsmen, who were habituated to observe the quality of raw materials and to study and master the technique of production, came into power that the necessary socio-economic conditions were produced for large-scale progress in experimental sciences. It is not an accident that Robert Boyle, often called the father of modern chemistry, was a younger son of an Elizabethan merchant peer, and that the Royal Society was formally founded in 1662 by a number of such men in co-operation for the definite object of meeting the social needs in the field of scientific and technical advancement.*

* The writer desires to acknowledge his indebtedness to J. G. Crowther's *The Social Relations of Science* for the data on history of scientific development in Europe. The writer's interpretations differ in some respects. Sri P. C. Sengupta's paper on early Indian Mathematicians (1932) has also been utilized. References to authorities for other data have been considered superfluous and have been left out.

IX. THE STUDY OF ARCHAEOLOGICAL PLANT REMAINS AND ITS SIGNIFICANCE

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1. INTRODUCTION

The desire to know the history of one's forefathers appears to be a human weakness. The historians have played a great part in fulfilling this desire of mankind. No less important are the contributions made by the archaeologists who, by excavating sites of various prehistoric civilizations, have reconstructed bit by bit the life that was led by the people of the remote past. In this way, information on our forefathers has been gathered from the time they lived a nomad life up to the present stage of our civilization.

The methods used by archaeologists for their study are well known. The remains of various civilizations are excavated and studied. Amongst these remains there are often some of botanical origin. Prior to the second quarter of the present century, the plant remains received rather limited attention. This was partly due to the difficulty of handling these fragile and extremely deteriorated materials. Often they were casually examined and reported upon by superficial looks. It was not thought either possible or necessary to examine these materials with the help of a microscope. As a result, many reports made on the remains of plant origin now appear to be doubtful and the conclusion drawn questionable. For instance, the report that the Egyptians wrapped their mummies in Indian muslin dyed in indigo was later refuted by Kennedy,[21] who by microscopic examination came to the conclusion that the material was linen—not muslin. Another example is the presence of teak in the ruins of Urs, and its significance on the commercial connection between Babylon and India.[18, 34] We have failed to find out the data based on which the wood remains from the excavation of Urs were identified as teak. Till the identity of the wood specimen is confirmed as teak with the help of modern technique, the question of commercial connection between India and Babylon at that time will remain unsolved.

The advancement made in microtechnique and plant anatomy during the last twenty-five years or so, has considerably widened the scope of this type of study. It is now possible to obtain clear and distinct anatomical structure from even minute fragments of plant material with the help of improved embedding and maceration methods. This, backed by our present knowledge of plant anatomy, has often led to recognition of undoubted identity of the archaeological plant remains. As a result of these studies during the last three decades, many plant materials have been identified and a flood of light has been thrown on various aspects of archaeological study, such as biological, climatic and cultural significance of the civilization under investigation.

2. AGE OF THE MATERIAL

Many methods are used to determine the age. Geologists were the pioneers in this field; they made use of stratigraphy to determine the time-scale of various epochs of earth's history. Since De Geer developed the 'Varve' analysis, the technique has been made use

of by archaeologists with a view to dating the materials of prehistoric origin.[18] The varve countings have been correlated with botanical plant remains, such as pollen grains, peats, etc. This study has thrown considerable light on the climatic phases of the locality in which the sediments were formed. By careful analysis of the data thus collected, it has been possible to draw conclusions on relative chronology of cultural events in relation to continuity of strata. This method is said to be reliable for only last 10,000 years.[36]

Another method is 'Tree-Ring Analysis'. This was developed by Douglass and his co-workers. The growth-rings of trees, and timbers recovered from the historic and prehistoric ruins of buildings, have been carefully studied by using the width and variation of growth rings as revealed in successive ring-layers from the pith to the periphery.[10] By projecting the peculiarity of the growths exhibited by the living trees and 'cross-dating' them, Douglass was able to give definite date to several prehistoric sites of America.[11] Other workers in Canada, England, Norway, Sweden and Germany have also done some research based on this method. All these studies have thrown light on the climatic conditions of some localities of the remote past. The species of trees studied by Douglass have been coniferous and that too in such zones where a slight climatic change was found to reflect on the width and other characteristics of the growth-rings. All conifers were not found equally helpful for this study. The best results were obtained from Western yellow pine (*Pinus pondorosa*) and Douglas fir (*Pseudotsuga taxifolia*). With our experience of Indian pine, *Pinus longifolia*, growth rings do not appear to give such exacting data as has been found by Douglass. Effect of climatic condition on the growth-rings of *P. longifolia* shows that abnormally low rainfall usually gives a narrow growth-ring. But when the rainfall is more or less normal, the growth-rings may be narrow or wide; thus making it difficult to say from the study of the width of growth-rings whether the rainfall had been low or more or less normal. In the case of very heavy rainfall, a tendency for the formation of false growth-rings has often been noticed. It will, therefore, be seen that application of tree-ring analysis for archaeological material, by growth-rings of *P. longifolia*, is rather doubtful. As regards broad-leaved species of India it has proved to be an almost impossible task to find out any relation between the width of the growth-rings and the climatic conditions of the locality in which the trees grow. For instance, teak (*Tectona grandis*) trees grow in the south for about six months in the year but in the north it grows only for four months. Little difference can be found between the width and other characteristics of growth-rings in the timbers grown under such widely divergent climatic conditions as found in south and north India.[5] Teak, being ring-porous species, should have been one of the best for such a study but it is not of much help. In fact, there are many Indian trees in which clear growth-marks are not at all visible. It will, therefore, be seen that the method of tree-ring analysis is not a profitable field of study in India. However, careful investigation on Indian conifers might lead in the future to some information on the old civilization and climatic conditions existing in the Himalayas, but in the plains which is our main centre of old civilization there is not much hope for such a study to give helpful results because the trees here are mostly broad-leaved ones. The tree-ring analysis method has so far produced dating up to 1000 B.C.

The third method has been recently developed and is known as the 'radio-carbon' method. Libby and his co-workers[1, 2, 23-26] have worked on many ancient remains of wood, charcoal, cereals, etc. They have come to the conclusion that this is a safe and reliable method for estimating the age of ancient materials. Flint[12] considers this method very reliable up to the age of 20,000 years, while Le Gross Clark[9] is of opinion that 'the radio-carbon method of estimating antiquity is not sufficiently reliable (with the

present technique) for periods more than 40,000 years'. In any case, it is safe to say that the radio-carbon method is a new technique for determining the age of prehistoric materials up to, say, 30,000 years. There are some drawbacks in this method too. The present technique usually requires a fairly large quantity of material which is not often available in archaeological excavations. Furthermore, in a country like India, there are only a few laboratories which can take up such investigations.

It may be mentioned here that some authorities like Flint have found out that materials of plant origin such as wood and peat usually give 'consistent-reliable results, regardless of whether the samples had been collected from positions that were wet or dry'.[12] In view of this, botanists should not now hesitate to draw far-reaching conclusions, provided that they have made intensive study of their materials and collected accurate data.

3. Methods of study leading to identification

The laboratory methods play a great part in obtaining anatomical details that are necessary for identification. Seldom can one recognize at a glance the excavated remains; if not anything else, these at least show a change in colour. From the point of view of anatomists, the plant materials recovered by archaeologists may be classified under four main groups:—

(*a*) Materials which show only a slight change. In them, the general shape and the look remain more or less unaltered.
(*b*) Partially or completely charred materials.
(*c*) Fragmentary remains as a result of severe deterioration.
(*d*) Impressions left in some associated materials such as clay, mud and the like.

With (*a*) type of material, the first stage is to examine it with a hand lens ($\times 10$ or $\times 12$). This will reveal the general morphological characters showing whether it is leaf, or bark or fruit or stem, etc. This is usually followed by microscopic examination under the reflected light. Often a binocular microscope of 'Greenough' type is more helpful than a monocular. Here, if necessary, dislodging or dissections of individual organs may be done. The next is to prepare the material for microscopic examination. In this it becomes often necessary to remove coatings of vinyl acetate and shellac usually applied by the archaeologist for the preservation of the material. Toluene is often used to remove these coatings. Then sections are cut on a sliding microtome or with a hand razor. At this stage a pretreatment with dilute KOH or NaOH may be necessary to allow the material to regain as far as possible its original size. After this treatment a thorough washing in hot water is necessary. Sometimes in addition, a quick wash with ammonia water is also helpful. Sections finally obtained are stained and mounted in the usual fashion. When examined under the microscope, gum-like deposits may often be observed in some sections. To improve the visibility of various cell structure, it is advantageous to treat these sections in Stockwell's solution [20] before mounting. All these stages mentioned above may not be necessary for certain materials. The process can be shortened or followed stage by stage depending upon the nature of the material.

(*b*) Partially charred material can be broken off and the unaltered portions may be separated and treated as in the case of material discussed under (*a*). It is the entirely charred material which has to be handled with a different technique. To have a look at the internal structure of any material, the usual practice is to cut with a knife. This cannot be done with charcoal because it will not cut but split or crumble exposing an uneven surface. The best method is to snap the specimen with a jerk to get as uniform a surface

as possible. To examine the surface thus exposed, it is helpful to mount it on a mass of plasticine. Structure observed under the binocular microscope should then be recorded. All the measurements like shape and size of the organs, *e.g.* leaf, fruit, seed, etc.. should be taken at this stage with a view to reconstructing the original material. The next step is to cut sections for microscopic examination as laid down by Jeffrey [19] for coal, and Maby [27] for charcoal. We have found that treatment with carbolic acid gives better results than that with hydrofluoric or nitric acid. After this the material is ready for embedding. Whether it has to be embedded in celloidin alone or celloidin and paraffin depends upon the condition of the material and the details of the structure required by the worker. Here again, celloidin dissolved in clove oil gives better results than celloidin dissolved in alcohol-ether. Well embedded material can then be cut even on a rotary microtome.[8]

(*c*) Removal of mud from the fragmentary remains is a tedious job but it has to be done. Apart from washing in water, treatment with dilute hydrochloric acid or bleaching with hydrogen peroxide or potassium hypochlorite often helps in cleaning the material. Whether it requires single embedding or double embedding in celloidin and paraffin depends upon the state of deterioration of the plant remains. Good sections have been obtained both on the sliding and rotary microtomes showing beautiful structure in detail. Along with this, partial maceration of material with chromic acid or sodium hydroxide has supplied useful information on special characteristics of the elements like epidermal cells, vessels, fibres, etc. In certain cases Artschwager's peel method [3] or Barghoorn's sodium chlorite method [4] with modifications has also been found helpful.

(*d*) There are two ways to handle these impressions. Firstly, a plasticine mould can be made of the impressions exhibiting the external morphology of the plant material, such as size, shape and nature of the surface. Occasionally bits of plant tissue may also come off with the mould. In that case photomicrographs of these tissues may be possible as was done by Sahni [32, 33] with his material of rice spikelet on baked pottery from Khokrakot, Rhotak. Secondly, the celloidin peel method recently applied by us [6] on the plant remains from Harappa and Hastinapura has been found to be very useful. Peels were taken of the marks of the coffin left on the ground. Some of these peels contained fairly large-size pieces of wood. It was possible to cut these pieces into 10–15μ thick sections after single or double embedding. From the impressions of plant materials from the mud walls excavated from Hastinapura, both thick and thin peels were obtained. The thin peels examined under microscope showed detailed anatomical structure of epidermal cells needing no more cutting into sections whereas the big pieces were macerated in the usual way and cell structure was recorded.[8]

4. Significance of Study

(*a*) *Botanical significance*: The plant remains recovered from sites of early civilizations in which communications were not so well-developed as it is now, indicate to a great extent the local vegetation. Among these, there may occasionally be certain remains which could not have been available locally, for instance deodar wood (*Cedrus deodara*) in Harappa.[6] In such cases communications with the outside civilization can be the only reason for its presence. Generally speaking the then local vegetation provides information on the climatic conditions prevalent at that time. A comparative study of the vegetation of olden times with the present one gives some idea of the climatic changes that might have taken place during the intervening periods. Often the use of plants or plant products, that have been made by a particular civilization, gives important information as to

the stage of civilization they were in. Use of plant for the first time indicates lack of proper knowledge and thereby often inapt use. It is with experience that one gathers inherent qualities of raw material and ultimately learns its efficient use. A case in point is the use of rice husk in the mud walls of Hastinapura.[8] When rice was first utilized by the ancients for food, possibly the use of its by-products was not known to them. After some experience they might have come to know that rice-husks are good binders of soil and then used them in plastering the walls of houses. From these facts one would be inclined to draw the conclusion that the people of Hastinapura used rice as food more than 3,000 years ago.

Improvement of food plants all over the world is at present a problem of major importance. Plant breeders engaged in this task find it necessary to know the origin of our main cereals, *e.g.* wheat, barley, maize, rice, etc. Here archaeological remains from prehistoric sites supply very useful information. In Europe, Helbaek and co-workers[15, 16, 17, 22] have compared remains of wheat from all over Europe and British Isles and come to definite conclusion as to the antiquity of wheat and its gradual development to the present state. In U.S.A., similar work has been done by Mangelsdorf and Smith[25] on maize. They have reached the conclusion 'that a small eared type of maize was used for food in the southern United States, approximately 3,000 years ago'. Similarly other workers in America have studied remains of maize from the Chicama Valley, Southern Peru and have discovered a primitive type of agriculture there. From these investigations, Randolph[31] has concluded: 'At some remote period following the migration of Folsom man from Asia to North America from 5,000 to 10,000 years ago, the nomadic tribes that spread southward through the United States into Mexico and Central America assumed a more sedentary way of life and became dependent for food and clothing on a primitive type of agriculture. These early Americans discovered wild plants that were suitable for food. Various cucurbits, beans and primitive maize were most certainly among the food plants cultivated by the first farmers of the Americas.' Here at home, remains of wheat and barley have been reported from Mohenjo-daro[29] and Harappa,[35] but so far not so intensively studied as those from Europe and other countries. Discovery of rice[7] among the remains of Hastinapura is very interesting. According to Ramiah and co-workers,[30] rice is the oldest cereal under cultivation in India. But direct evidence for this statement in North India went, till recently, as far back as 100 B.C. The rice remains from Hastinapura now take us back to about 1000 B.C. However, it has not been possible for us yet to say definitely the closest affinity of this find with our present cultivated variety of rice.

The plant remains other than cereals are also interesting. The study of wooden poles from Kirari[14] and Pataliputra indicates the rate of deterioration of wood not contaminated by fungus or other agencies. The way the different cells in these poles gradually lost their original size and shape and ultimately collapsed, supplied information on the durability of timber in general. Examination of well-known timber in use for more than 2,000 years in the buildings and caves of India gave no less important data to the wood technologists.

(*b*) *Cultural significance*: Correctly dated and accurately identified remains produce a reliable basis for reconstructing the ways of life of ancient men and their efforts to make the best use of the environments. In a way history is built up for a time when no records were kept or written. Data collected by this method enable one to find out the continuity or otherwise of certain practices. Contact of different civilization can also be traced by analyzing the information thus collected. Before intensive excavation of Mohenjo-daro and Harappa, it was not realized that some highly advanced civilization

existed in North India with least influence of Indo-Aryan culture. In the words of Marshall,[29] 'the Indus culture corresponded in its general features with the Chalcolithic cultures of Western Asia and Egypt. In other respects, however, it was peculiar to Sind and the Punjab and as distinctive of those regions as the Sumerian cultures of Mesopotamia or the Egyptian of the Valley of the Nile'. These conclusions were further confirmed by a recent discovery of coffin burial for the first time in Harappa. Examination of the timbers used for coffin revealed some interesting information.[6] For coffins, in Mesopotamia and Egypt, usually scented woods such as cypress, juniper, pine and cedar (*Cedrus*) were used. The coffin at Harappa was made of deodar (*Cedrus deodara*) and rosewood (*Dalbergia latifolia*). The point to note here is that the coffin from the Indus Valley was also made of scented woods—deodar (*Cedrus*) used by the contemporary civilization of Western Asia and Egypt, and rosewood, a local timber. The use of a local scented rosewood indicates the distinctiveness of Indus Valley civilization, as against those of Mesopotamia and Egypt. Study of such nature often reveals interesting data that enable one to draw reliable conclusions.

Another important aspect of this study is to check up the statement made in the Puranic literature. Much has been written about the fauna and the flora of ancient India. Direct evidence is always welcome for confirmation or otherwise of the statements made therein.

In summing up it may be said that the study of archaeological plant remains is a profitable line of research, especially for the prehistoric civilizations. The present techniques of determining the age of the remains are fairly reliable. The laboratory techniques of handling plant remains have now advanced enough to give accurate data to determine their identity. Based on these advancements, the conclusions drawn would, at the present time, appear to be more reliable than hitherto.

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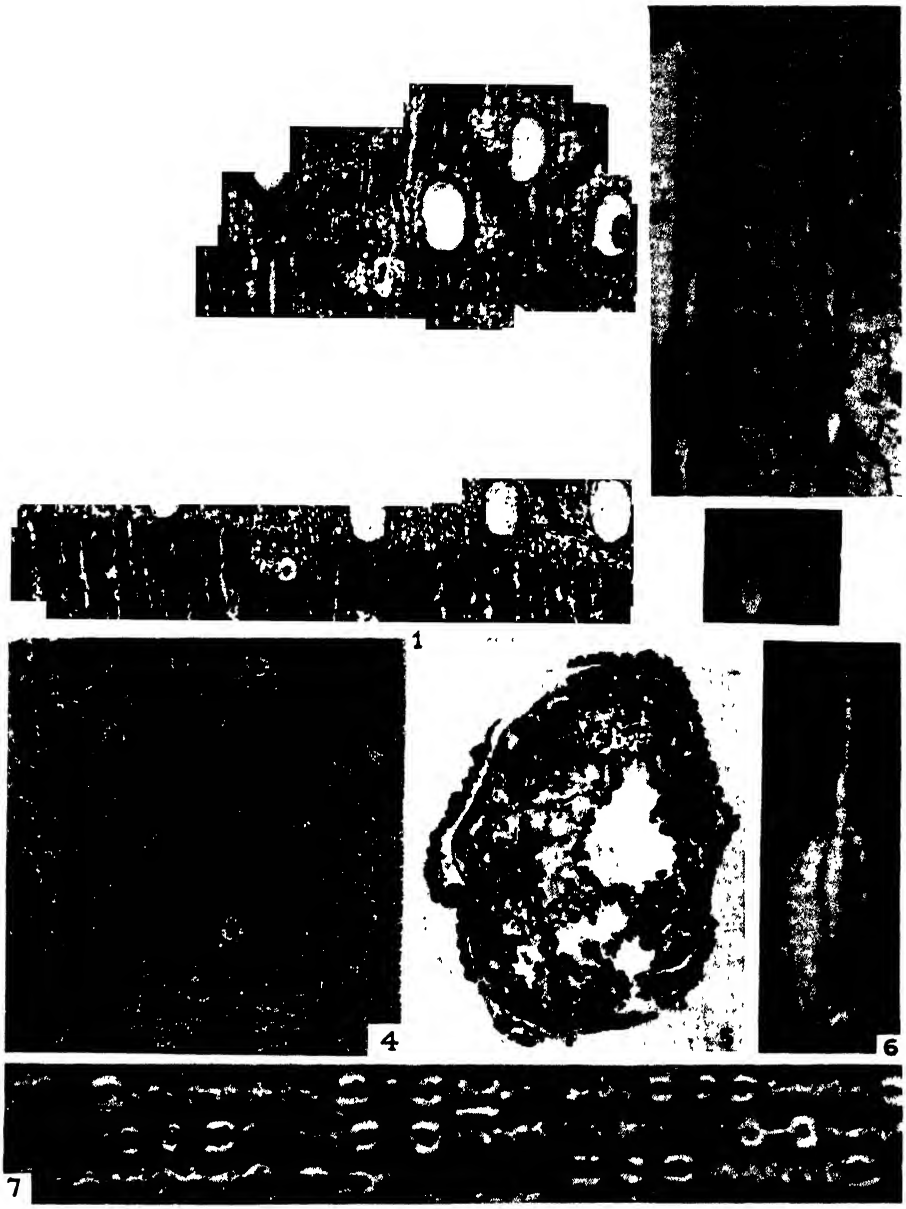

FIG. 1. Cross-section of charcoal, about 2,000 years old. Note distinct pattern of soft tissues round pores; growth marks are clear due to initial parenchyma cells. (×50)

„ 2. Radial section of *Cedrus deodara*, at least 4,000 years old. Note scalloped margin of the tori of bordered pits. (×450)

„ 3. Rice grains, about 3,000 years old. (×3·5)

„ 4. Leaf sheath epidermis of *Saccharum spontaneum*, about 2,800 years old. Note shape and size of long epidermal cells (*L*), silica cells (*Sc*), cork cells (*C*), spicules (*Sp*) and stomata (*S*). (×300)

„ 5. Cross-section through the middle of charred rice spikelet, about 3,000 years old. (×30)

„ 6. Charred rice spikelet with awn. Age 3,000 years. (×8)

„ 7. Portion of highly magnified lower leaf epidermis of *Saccharum spontaneum*. Age about 2,800 years. Note halter or dumb-bell shaped silica cells and long epidermal cell (*L*). Phase contrast (×600)

X. THE FOLIAGE LEAF AND THE AXILLARY BUD *

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THE FOLIAGE LEAF

In 1606 Adrian Spieghel wrote in despair—But what is the leaf? Long and oft have I sought an answer to this question without finding anything with which I could satisfy you and myself. (Arber, 1950, p. 72.)

Three hundred and forty-eight years have passed and, I think, we are still unable to give a satisfactory answer to the question that disturbed Spieghel. It is, however, not difficult for a botanist to describe the foliage leaf. But what is its morphological status? Is it an 'entity *sui generis*', or is it an integral part of the stem on which it is borne, and the two together form the unit of construction of the body, called the shoot?

There are two opposite views held by morphologists regarding the status of the foliage leaf. According to the oldest conception the caulome, phyllome, rhizome and the trichome 'co-operated in the construction of the vegetative system' of a plant. Those who hold this view consider the foliage leaf as an independent unit, an entity *sui generis*. Troll in his great book, *Vergleichende Morphologie der höheren Pflanzen*, (1935–1939) described the leaf as the *Grundorgan*, an ultimate 'given' element in the construction of the body, and that the root and the stem are equally basic. This view is strengthened by the fact that the leaf has many individualities (including its fall) which distinguish it from the other two basic organs. On this view, much earlier, Goethe propounded and elaborated his Metamorphose Theory in 1790 (see Arber, 1950, chap. vi.)

The other view is also very old. According to this view the stem and the leaf together form a unit, the *shoot*, and lead a unified existence of their own being bound to each other by the vascular system. This conception is based mainly on the nature of the vegetative bud which behaves like a unit structure for the shoot. Sachs realized this position of stem and leaf when he said that 'stem and leaf denote certain relationships of the parts of a whole—the shoot'. Again in 1882 in his *Lectures on the Physiology of Plants*, he wrote: 'the shoot includes both stem and leaf, and forms the real unit'. Tansley (1951) admits that Sachs' dictum is indisputable (p. 402).

Both as an entity *sui generis* and as a component part of the shoot the leaf is being treated in modern text-books, and we find the use of such terms as, the vegetative shoot, flowering shoot, shoot apex, etc. But in 1941, and again in 1950 Arber propounded her Partial-shoot Theory to explain the morphological status of the foliage leaf. According to this theory 'the foliage leaf is a partial-shoot, arising laterally from a parent whole-shoot', with the corollary that 'it has an urge towards the development of whole-shoot characters' (1950, pp. 74, 78).†

The Rhyniaceae had no leaves, no roots, but the body consisted of a dichotomously branched axis. Thus a photosynthetic shoot existed as a morphological unit before it

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* I have utilized for my purpose much of the informations given in chaps. vi, vii, and viii of Dr. A. Arber's *Natural Philosophy of Plant Form*, 1950. It is my pleasure to record here my indebtedness to her.

† For evidence and arguments advanced in support of her theory the reader is referred to chaps. vi, vii and viii of her book, *The Natural Philosophy of Plant Form*.

segregated into its component parts, the leaf and the stem. This led Tansley to point out that there was a time when the foliage leaf was not yet differentiated in the sporophyte. The foliage leaf, therefore, must have had an evolutionary history of its own. This history has been traced to the Rhynia Flora (Zimmermann, 1930). Arber proceeded to establish her theory on the premises that the leaves of ferns and angiosperms are homogenetic, and that they are cladophylls or cladode leaves. But Tansley thought that in order to establish her thesis Arber should have taken into her consideration the origin and nature of leaf-like organs and leaves of lower groups of plants, such as, Algae and Bryophytes. But Bower (1935) holds a different view. He thinks that foliar development has pursued a separate course in the haploid and diploid phases of each Archegoniate life-cycle. So the foliar development in the gametophytes and sporophytes will be homoplastic and not homogenetic, and each should be considered as separate problem of evolution though the conditions underlying the origin of both may have been alike, as are also the results.

Even if we consider the origin of leaf-like organs in alga, like *Caulerpa*, and of leaves in the foliose Jungermanniales and Mosses, it is not difficult to refer them and the axes which bear them, to a common origin from a thallus body. In Mosses the same segment, cut off from the apical cell of the leafy gametophore, gives rise to both the leaf and the axis together. The origin of lateral organs is merely an elaboration of the body for photosynthetic purposes.

In the sporophytes of Pteridophytes we come across two different types of leaves, namely, the microphylls and the cladophylls. Microphylls characterize the great groups of plants: the Psilopsida, Lycopsida and the Sphenopsida. For their evolutionary history the reader is referred to Bower (1935).

The cladophylls, on the other hand, characterize the Pteropsida which include the Ferns, Gymnosperms and the Angiosperms. They are, as the name indicates, equivalent to a branch system. This has been well established by both palaeobotanists and plant anatomists. Potonie found no difference between a branch system and the fern leaf. Tansley (1908) from his extensive studies on the vascular system of ferns came to the conclusion that 'the fern leaf is in phylogenetic origin a branch system . . . . and not an appendicular organ differing *ab initio* from the axis on which it is borne'. He affirms further that 'the foliage leaf retains many characters of stem'. *Polypodium proliferum* grows wild in Bengal. Its frond is provided with an apical meristem, similar to that of its stem, and buds develop in the axil of its leaflets. All these support not only the partial-shoot nature of the foliage leaf, but also its *urge* towards whole-shoot character. Arber ascribes this partial-shoot-hood to cessation of apical growth and loss of radiality early in the ontogeny of the leaf.

If, therefore, Arber has traced the origin of the foliage leaf from the fern frond one cannot or should not accuse her that she has treated the problem of the morphological nature of the foliage leaf in 'isolation', unless as pointed out by Newman (1949) * that the leaves of ferns and angiosperms are quite different in nature.

The partial-shoot nature of the leaf may be supported on the results of experiments. If a leaf is cut from the parent plant and planted in soil or water like stem-cuttings, it will produce roots from the cut-end. This root production can be enhanced by the application of artificial growth-promoting substances. Though such leaves will produce roots

* Newman (1949) has separated the Pteropsids into two groups, namely, Filicopsida and Spermatopsida, on essential difference between the leaves of the ferns and angiosperms.

easily from the base of the petiole they will not as easily produce shoots. But cases are on record, though rare, where leaf-cuttings have produced shoots under cultural conditions. Goebel reported the production of new shoot buds from the petiole and cut mid-vein from severed leaves of Achimenes. Leaf-cuttings of potato are also known to give rise to shoot buds. The reason for easy root production than that of shoot buds is quite explicable. Roots take their origin in the cambium of the petiole (endogenous origin) whereas the upper part of the petiole is rather mature with a cuticularized epidermis. Mitra of Delhi University is experimenting on the regenerative power of certain herbaceous leaves, and is trying to induce shoot-bud production by the application of various growth-accelerating substances attended with surgical operation. He informs me that he found it easy to regenerate shoot when the severed part contained apical meristem.

The Axillary Bud

If the leaf is a partial-shoot how one is to explain its close association with the whole-shoot, *i.e.* with the axillary bud? Is the axillant leaf a part of the bud in its axil, or does it belong to the main shoot as the latter's component part?

The ontogenetic studies of the leaf show that it is a part of the axis which bears it, and that the two together form the shoot (Mitra and Majumdar, 1952; Majumdar, 1948; Saunders, 1922; Hofmeister, 1851). If that is so, how are we to account for the close leaf-bud association in higher plants?

Warming (1872) suggested an answer to this question. He wrote that the axillant leaf and its bud together constituted one unit; the axillary bud belonged quite as much to the axillant leaf as to the parent axis, and that it was indeed in great part a development of the leaf base. He also held that the axillant leaf might be treated as the first and the only leaf of the axillary bud, while the succeeding leaves, apparently belonging to this bud, are really borne by the buds of the next order (from Arber, 1950, p. 125).

Arber, however, gives and develops a very ingenious explanation of the origin and nature of the axillary bud. She suggests: 'A typical leaf is a shoot in which the apex is limited in its power of elongation and in its radiality. Failure in lengthening arouses tripartite character in the leaf . . . . it seeks to compensate itself by diversion into a basal branch on either side, while the failure in radialness brought about by inactivity on the adaxial face of the tip, induces a dorsiventral character, though a residual urge towards the radiality of whole-shoot-hood also persists (pp. 125-26, 1950).

'Axillary bud should be regarded as a direct outcome both of the tripartedness and of the urge to radiality, which are such fandamental features of the leaf. The axillary bud may be pictured as equivalent to two branches (lobes or pinnae) produced from the basal region of the axillant leaf, on either side; these branches must be visualized as in a state of face-to-face fusion in front of the parent leaf. Though they each, as segments of the leaf, would be of dorsiventral organization, they achieve radiality by their union' (p. 126).

According to Arber the shoot consists of closely linked series of whole and partial shoots (*cf.* Warming, above). The plumular whole-shoot bears leaves (partial-shoot), each of which may give rise to an axillary bud (whole-shoot) which again produces partial shoots. This alternation may proceed indefinitely. *Lateral bud is thus the offspring of the leaf, the partial shoot,* i.e. *the product of its united basal lobes* (p. 126).

Indirect proof comes from evidence based on anatomical investigations. In the majority of investigated cases of bud vascularization it has been found that the bud traces

are two in number, and they are supplied from the margins of the gap left in the central cylinder by the median trace of the axillant leaf. They stand face to face and then by branching form a ring of bundles at the base of the bud enclosing a part of the pith of the parent axis. What is the morphology of the part these bundles serve?—asks Arber. The face-to-face approach of the two bundles arising from the sides of the leaf gap, and their ensuing divisions to produce a radial system from the two dorsiventral systems, are completely compatible, Arber maintains, with the fusion of a basal pair of leaf branches which she has pictured as responsible for bud formation (p. 127).

This interpretation of the origin and nature of axillary bud may be supported by an example. The morphological nature of the fertile spike of *Ophioglossum* is still a matter of dispute. Chrysler (1910) worked out the vascular supply to this organ, and supported the *pinna origin* of the fertile spike, produced by the fusion of the pair of basal pinnae of the only leaf bearing the spike on its adaxial surface. If this interpretation of the origin and nature of the fertile spike can be accepted on anatomical evidence alone, there is no reason why Arber's interpretation of the origin and nature of the axillary bud should be ignored (see chap. viii, 1950).

It should, therefore, be admitted that Arber's interpretation is very clever and thought-provoking, and supported by anatomical evidence.* But the evidence produced in support of her thesis is indeed slender and indirect. Actual proof, Arber herself admits, for such a theoretic conception as this of the axillary bud can scarcely be hoped (p. 126).

Within recent years large amount of investigations have been carried out on the ontogeny and development of axillary buds, but in none of them the slightest indication is made to show that the axillary bud is the *offspring* of the leaf that bears it. (Garrison, 1949*a*, 1949*b*; Gifford, 1951; Hsü, 1944; Kundu and Rao, 1954; Louis, 1935; Majumdar, 1942; Majumdar and Datta, 1946; Mitra, 1952; Philipson, 1949; Reeve, 1943; Saha, 1954; Sharman, 1945; Snow and Snow, 1942; Wardlaw, 1952*a*, 1952*b*, and others.)

Axillary buds have been reported to take origin in two ways: (1) from the axis (origin, axial), and (2) from the leaf primordium (origin, foliar). In the axial origin the bud is initiated in the *detached meristem* which is 'a group of cells which at one time formed part of the apical meristem and which have retained their meristematic potentialities' (Wardlaw, 1952). The other method of origin, *i.e.*, foliar, takes place in previously vacuolating dividing tissue of the leaf primordium (Majumdar, 1942).

Bud traces may originate from the axial cylinder and their differentiation to bud meristem, acropetal (Louis, 1935, and others), or their origin may take place in the primordium itself, and the connection with the axial cylinder is made basipetally (Majumdar, 1942, and others).

Whether axial or foliar in origin, and whether the trace differentiation is acropetal or basipetal, the number of bud traces is always two, they stand face to face, and enclose a core of tissue which belongs to the pith of the parent axis.

* Dr. Arber is evidently not satisfied with her own interpretation. In personal communications she writes: '.... we might get from you a detailed and general study of the relation of the axillary bud and the leaf. I am myself not at all satisfied with the theory which I propounded in my book (1950), and I hope that you may, on the basis of your own studies—provide us with a better explanation.' In another letter she wrote: 'I shall be interested to see in your further work exactly how you relate the axillary bud to the general shoot development.' In the body of this paper I have quoted her extensively even without quotation marks.

When the origin is axial there is no indication that the bud is the offspring of the axillant leaf, but the foliar origin indicates closest relationship between the two.

Is it possible to suggest, on the data presented above, any other workable hypothesis to explain the morphology of the axillary bud and its close association with the axillant leaf? Before we venture to give one it is necessary to discuss the Telome Theory of Zimmermann (1930).

Zimmermann developed his theory (accepted by Bower, 1935) from a study of the Rhyniaceae, the earliest vascular plants. The telomes or the ultimate branches (no leaf yet) may be sterile or fertile. They were photosynthetic shoots. Ontogenetically they were alike and radial in construction (*cf.* mid-rib region of the foliage leaf; in a particular variety of Croton leaves are found with some portion of the mid-rib without wings). The radial sterile telomes by the development of wings from their sides (pleuroplastic development), and uniting with similar other telomes, became flattened and dorsiventral to expose more surface to solar energy for photosynthetic purposes.

This is the accepted hypothesis of the origin of foliage leaf in higher plants. They are called cladophylls because their origin can be traced to the branch systems of the Rhynia Flora. According to this theory both leaves and branches are initially shoots. But the leaf is a shoot *per force* partial, because it loses its apical meristem very early in its ontogeny. The growth of the wings is regarded by Arber as a compensation for this disability.

We have shown elsewhere (Mitra and Majumdar, 1952) that the stem bearing leaves is made up of a core enclosed by a mantle. The core is the pith and should be regarded as cauline. The mantle which includes the cortex and the vascular tissues is made up of the base or bases of leaves united together, and is to be regarded as foliar.

On this interpretation of the stem all the tissues outside the pith belong to the leaf. The detached meristem which gives rise to the bud is, therefore, superficial and belongs to the base of the leaf. This explains the superficial or cortical (exogenous) origin of the bud.

In the Rhynia Flora the primary forking of the axis is a dichopodial development (dichotomy is the prevalent mode of branching in the early vascular plants). This dichopodial type of branching is the first step in the segregation and differentiation of the body (shoot) into the stem and the cladode leaf. They are associated together from the very beginning of their origin. * So far there is, therefore, no difference between Arber's partial-shoot nature of leaves and their origin and development from the branch system of the Rhynia plants. The cladophylls share a common origin with the stem, and they, the bud and its axillant leaf, should be regarded as *twin sisters*, and not as the mother and her offspring. They came into being simultaneously (see also Bower, 1935, pp. 562-63).

It may now be suggested as an alternative to Arber's hypothesis that the initials (group of mother cells) of the axillary bud and the axillant leaf, both products of the same apical meristem, represent the two primordia of a distal forking. The outer one (positional) develops quickly and rapidly to form the leaf primordium under the influence of its acropetally differentiating median strand (Majumdar, 1948) which follows its erection closely. The other (inner) remains undeveloped until its traces come from the

* For method and steps of progression from equal distal dichotomy, by gradual steps of inequality, to the development of a central axis with lateral appendages, see Bower, 1935, p. 550.

axial cylinder a little later than the median trace bundle of the leaf. This perhaps explains, their close association and time difference in development.

We have already seen that Arber derived indirect support to her basal-lobes theory of the nature of axillary bud from the behaviour of the bud traces. Vascular supply to the leaf and its branches (lobes or pinnae) has been worked out though not very thoroughly. The supply to the leaf branches come from the lateral leaf-trace bundles and not from the median. The origin of bud traces and their supply to the bud do not indicate their connection with the axillant leaf. But the origin and subsequent behaviour of the bud traces support the axial nature of the bud.

If the dual nature of the bud axis is accepted (Mitra and Majumdar, 1952) then cauline pith should be enclosed. This is easy to do when the bud traces originate from opposite sides, stand face to face and then resolve into a ring of bundles enclosing a portion of the parent pith (cauline). In this connection the behaviour of the lateral and median trace bundles in the petiole may be visualized. A single bundle would not be able to do this.

In the case of foliar origin the bud is initiated, as we have said before, in the vacuolating dividing cells on the adaxial surface of the primordium just opposite the median bundle, and its differentiation is from the epidermis inwards. The mid-rib region·which contains the median bundle is equivalent to the primary axis of the fork or the telome. The only interpretation that I can offer at this stage is that (1) the two branches (distal forkings) of the short shoot grow together for some distance before they separate, or (2) the base of the leaf primordium splits (chorisis) into two branches (*cf.* Warming). More work is necessary before any explanation with evidence could be offered.

Conclusion

1. Arber's partial-shoot theory of the leaf is discussed and supported.

2. Her interpretation of the nature of axillary bud, *i.e.* its origin from the pair of basal lobes of the axillant leaf, is examined, but not fully supported.

3. It is suggested that the axillary bud and its axillant leaf are twin sisters (a pair of distal forkings) of a dichopodial shoot, as an alternative to the offspring-mother interpretation of Arber.

4. In suggesting the alternative hypothesis the following points have also been discussed:—

(*i*) The close association of the axillary bud and its axillant leaf, and
(*ii*) the behaviour of the bud traces.

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XI. MINERALS IN RELATION TO LIVING STANDARDS

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Minerals form one of the modern world's most important resources in the support and enrichment of human life. Minerals and ores have formed the basis of the world's industrial civilization for the last century and a half, as a great proportion of the world's work is done by means of tools which are made, directly or indirectly, out of minerals and metals. Modern defence armaments and ammunitions, together with the new atomic weapons, depend more or less entirely on the products of mines. This has caused great inroads in the world's stock of minerals, in some cases to such an extent that their accessible stocks in the earth's crust have almost reached depletion point. A serious question arises whether in the coming centuries the reduced supply of minerals will affect, and to what degree, man's living standards. In this depletion of the earth's stock of minerals wars have played a momentous part. The wars of the present century have used up more basic metals and minerals than was consumed during the whole course of human history. The diminishing reserves of such minerals as petroleum, lead, tin, zinc, etc., have called forth warning notes from geologists and economists. But it is evident that the tempo of consumption of minerals is steadily rising and will increase to such an extent before the twentieth century closes that mankind will be fronted with problems of replacement of some depleted minerals by non-mineral products, such as plastics, glass, ceramics, etc. Doubtless in some measure, the substitution of plastics and alloys of the lighter metals, which are in more abundant supply, together with new discoveries of mineral reserves in hitherto unexplored territories of the world, resort to deeper mining and developments in ore and mineral refining techniques, may put off the time of scarcity for two or three generations, but the lesson of mineral depletion from the accessible parts of the earth's crust should be taken as nature's grim warning that modern man is spending away a prime potential which is non-replaceable. How this will affect the trends of man's progress and civilization eventually, or in what manner human ingenuity, science and technology will be able to meet this challenge and overcome the threat, is difficult to foresee.

To the extent that India has remained backward in the world's industrial race and has not participated actively in the wars of last century, her mineral wealth has not been drawn upon so wrecklessly. This may apply in a greater or less measure likewise to the countries of Asia and the whole of the East.

There are roughly about 2,000 species of known minerals and of these 200 at most are of direct or indirect use to man's pursuits and find application in commerce, industry and arts. These economic minerals are further classified into strategic minerals, critical minerals, key minerals and the remaining common minerals, although the distinction is not rigid and is fast disappearing. For practical purposes every country looks at its mineral resources from the viewpoint of its surpluses, sufficiencies and deficits in the totality of its assured and probable reserves. It is a sign of the times that today every great world power looks at its mineral situation from the viewpoint of military strategy

and internal defence. There is a rapidly mounting list of what are classed as rare minerals and metals which are brought into use in the manufacture of munitions of war; as for example, the new atomic weapons of warfare, jet-propelled engines, rocket planes and highly specialized electronic applications of strategic use. The most important minerals, therefore, today are the minerals which are on the defence programme of a nation under the present conditions of totalitarian war—for use in munition and an amazing range of ferrous and nonferrous alloys, fluxes, refractories, and accessories. These are stock-piled and earmarked for war emergency and are regarded as minerals of prime importance. The second class are ores of rare metals and earths and non-metallic minerals and their compounds which feed the demands of modern highly specialized industries and the third group comprises all the rest of the metallic and non-metallic natural products which supply the needs of everyday life and of international commerce. In the coming years atomic metals—uranium, thorium, lithium, zirconium and a number of subordinate mineral substances required for the production and utilization of nuclear power, as integral structural or shielding parts of atomic reactors, will gain rapid prominence. Use of atomic energy as a source of industrial power within very near future can be confidently predicted. This is a new phase of human endeavour. The world's resources of uranium are not so scanty as was at one time supposed and the present-day strides in nuclear physics research will tend more and more towards using the energy sources for industrial power from nuclear fuel rather than fossil fuel. This will relieve pressure on the fast diminishing reserves of fossil fuels—coal, petroleum and gas which, according to competent authorities will not be able to support the increasing demands for their consumption for more than 8–10 decades, even in the countries best endowed with these resources.

From the world's mineral map we see that while India has assets of great importance in iron, manganese, aluminium, titanium, thorium and mica, the catalogue of deficiencies is also impressive, in some respects serious, *viz.*, petroleum, sulphur, copper, tin, lead, zinc, nickel and potash. While in the former group India occupies a commanding, if not controlling position, in the latter the position is one of dependence on foreign imports. There is an intermediate group of minerals in which India is self-sufficient, for the present and the immediate future, *viz.*, in her resources of ferro-alloy metals, fluxes, rare-earths, refractories, abrasives, bauxite and industrial clays. This disequilibrium in the country's economy—large assets in some categories and serious gaps and deficiencies in others, is not harmful in times of peace, but in the event of war, lack of the chief deficit minerals, even though relatively unimportant in themselves, may imply grave hazards to the country's security. A healthy economy, both for peace and war, can be achieved on the pattern evolved by the U.S.A.: (*i*) by balancing, as far as possible, surpluses against deficits by a system of exchange or barter with the industrially more advanced countries; (*ii*) through building up a strong civilian peace-time industrial power; (*iii*) production of synthetics and substitutes for deficient and submarginal commodities; and (*iv*) stockpiling of some ten essential deficit minerals and raw products for emergency use.

Germany and Japan may be cited as examples of countries who have reared a great industrial civilization and fought two world wars without possessing appreciable internal mineral resources. They depended on free internal commerce in peace-time and on hoarded ammunitions and strategic materials in war. This was possible because of their long and well calculated planning and the long lead they had in pre-war years in accumulating stockpiles of important raw materials.

We thus see that minerals have raised the living standards of the people of the world and greatly enhanced man's prowess. It is an irony that this prowess is applied equally in

fighting evils like diseases, famines and poverty, at the same time also in destroying his fellow-creatures in wars. A too free use of this gift of nature is thus not unattended with danger to man's progress and civilization, if not to his very existence. The numerous warnings sounded from many sides during the last few years against the use of atomic weapons in warfare and the cry against wreckless use of fuels, metals and other irreplaceable minerals are timely notices that this may ultimately result in lowering man's living standards and his status in the scale of universe.

XII. SURVEY OF FUNGUS-FLORA OF INDIA IN SEARCH OF ANTIBIOTICS

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Introduction

One hundred species of Indian fungi, mostly higher fungi (*Basidiomycetes*), isolated in this laboratory and obtained from other sources, have been screened against *Staphylococcus aureus*, *Bacillus typhosus* and *Escherichia coli*. The method of assay was Wilkin's (1949) 'hole in plate' method. The organisms have been classified as: (1) strongly positive (+++), *i.e.*, giving inhibition-zones of 19 mm. and above; (2) positive (++)—giving zones of 17 mm. to 19 mm.; (3) weakly positive (+)—giving zones of 12 to 17 mm. and (4) negative (−). The details are shown in Tables I and II.

The fungi belonging to the 'strongly positive' group (*vide* Table II) which appeared more promising than others, were investigated in detail. The results of these investigations are summarized below.

Experimental Results

1. *Psalliota campestris*.

This fungus, which proved to be the most promising of the 'strongly positive' group, was investigated in fuller detail. In order to study the effect of the substrate on both growth and antibiotic activity, the following culture media were tried: (1) 3% malt with and without vitamins; (2) Czapek-Dox medium with 2% glucose and supplemented by malt or soil extract; (3) maltose-casein-yeast liquid medium with or without vitamins; (4) cornsteep liquid medium 0·5% or 3% with 0·5%, 1% and 2% glucose or maltose supplemented by phenylacetic acid, sodium citrate or cobalt chloride; (5) peptone-beef extract-dextrose liquid medium; (6) pea broth; (7) linseed oil cake medium 0·5% or 1%; (8) cotton seed liquid medium 0·5% or 1%; (9) kapok oil cake medium 0·5% or 1%; (10) *Vasak* (*Adhatoda vasica*, Nees) leaf extract medium; and (11) whey liquid medium with and without glucose. Except when otherwise mentioned, glucose was kept at a 2% level and the *p*H of the medium was near about 6·2.

Of all these, 0·5% cornsteep with 2% glucose was found to be the best as regards growth and antibiotic activity.

Addition of vitamin B_1 in different doses to the culture medium had varying effects on growth, increasing it in some cases, decreasing it in others, and in some cases having no effect at all. Vitamin B_1 was found to have no effect on antibiotic activity, contrary to expectation.

Exposure to ultraviolet radiation had the effect of producing faster-growing mutants, and one of these strains showed a marked increase in antibiotic activity in addition to growth, when compared with the parent strain. A strain from Indian Agricultural Research Institute, New Delhi, was also studied, but it was poorer in antibiotic activity than the Calcutta strain.

It was found that during active growth and antibiotic production 0·2% to 0·4% sugar was utilized but the starting concentration of sugar (dextrose) had to be 2% if antibiotic activity was to be obtained.

TABLE I

Total list of 100 species of fungi tested for antibacterial activity for four and a half years from September, 1949 to December, 1953.

Activity assayed by Wilkin's 'hole-plate' method, in bulk-seeded plants, diameter of hole being 8 mm.

Species of fungi tested	Test organisms: Gram-positive		
	Gram-positive	Gram-negative	
	S. aureus	*B. typhosus*	*E. coli*
A. *Basidiomycetes*			
I. *Thelephoraceae*			
1. *Grammothele effuso-reflexa*	–	–	–
2. *Stereum* sp.	+	+	+
II. *Auriculariaceae*			
1. *Hirneola cornea*	–	–	–
III. *Hydnaceae*			
1. *Irpex flavus*	–	–	–
IV. *Agaricaceae*			
1. *Lentinus subnudus* 1949	–	–	–
2. *Lentinus praerigidus* 1949	++	++	++
3. *Lentinus revelatus* 1949	++	++	++
4. *Lentinus revelatus* (new isolate 1950)	–	+++	+++
5. *Lentinus subnudus* (new isolate 1950)	++	++	++
6. *Lentinus praerigidus* (new isolate 1950)	–	+++	+++
7. *Schizophyllum commune* 1949	–	–	–
8. *Schizophyllum commune* (new isolate 1951)	+	+	+
9. *Marasmius campanella* 1949	–	–	–
10. *Marasmius campanella* (new isolate 1951)	+++	++	++
11. *Psalliota campestris*	+++	+++	++
12. *Psalliota campestris* (New Delhi strain)	++	++	++
13. *Psalliota campestris* (1953 isolate)	++	+++	++
14. *Psalliota campestris* (1952 isolate)	+	++	+
15. *Psalliota campestris B.* and *Lepiota mastoides*	–	++	+
16. *Volvaria diplasia*	+++	+++	+++
17. *Flammula dilepis*	+++	+++	+++
18. *Armillaria mellea*	+++	+++	+++
19. *Lepiota mastoides*	+++	+++	+++
20. *Collybia albuminosa*	–	++	+
V. *Polyporaceae*			
1. *Polyporus ostreiformis* 1949	–	–	–
2. *Polyporus ostreiformis* (new isolate 1951)	+	+	+
3. *Polyporus ostreiformis* (new isolate 1952)	+	+	+
4. *Polyporus ostreiformis* (new isolate 1952)	–	–	–
5. *Polyporus gilvus*	+	+	+
6. *Polyporus gilvus* f. *licnoides*	+++	+++	++
7. *Polyporus gilvus* f. *gilvoides*	+++	+++	++
8. *Polyporus schweinitzii*	+++	+++	+++
9. *Polyporus zonalis*	+++	+++	++
10. *Polyporus conchoides*	–	–	–
11. *Polyporus adustus*	+++	–	–
12. *Polyporus cuticularis*	+	–	–
13. *Polyporus anebus*	–	+++	–
14. *Polystictus sanguineus* (monosporous isolate C.U. white strain)	+++	+++	++
15. *Polystictus sanguineus* (X-rayed)	++	++	++
16. *Polystictus sanguineus*	++	++	++

TABLE I—*Contd.*

Species of fungi tested	Test organisms		
	Gram-positive	Gram-negative	
	S. aureus	*B. typhosus*	*E. coli*
V. *Polyporaceae*—Contd.			
17. *Polystictus sanguineus* (monosporous isolate No. 5 of C.U.)	–	–	–
18. *Polystictus sanguineus* (monosporous isolate No. 14 of C.U.)..	–	–	–
19. *Polystictus hirsutus*	–	–	–
20. *Polystictus steinheilianus*	+	+	+
21. *Polystictus xanthopus*	+	+	+
22. *Polystictus zonatus*	–	–	–
23. *Polystictus versicolor*	–	–	–
24. *Poria xantha*	+	+	+
25. *Poria monticola* (Dehra Dun)	+	+	+
26. *Trametes cingulata* 1949	–	–	–
27. *Trametes cinnabarinus* 1949	+	+	+
28. *Trametes persooni*	–	–	–
29. *Trametes cingulata* (new isolate 1951) ..	+	+	+
30. *Trametes lactinea*	+	+	+
31. *Trametes badia*	++	+++	+++
32. *Trametes cinnabarinus* (new isolate 1951) ..	+	+	+
33. *Trametes cubensis*	+	++	++
34. *Trametes versatities*	+	+	+
35. *Hexagenia tenuis*	–	–	–
36. *Hexagonia gunni*	+	+	+
37. *Daedalea flavida*	–	–	–
38. *Daedalea microzona*	+++	+++	+++
39. Fruit body of *Daedalea unicolor* ..	–	–	–
40. *Lenzites striata*	–	+	+
41. *Lenzites repanda*	–	+	+
42. *Lenzites saepiaria*	+	+	+
43. *Lenzites betulina*	+++	–	–
44. *Fomes pachyphloeus*	–	++	–
45. *Ganoderma lucidum*	–	++	–
46. *Ganoderma applanatum*	–	+++	–
47. *Favolus scaber*	–	–	–
VI. *Agaricaceae* and *Polyporaceae*			
1. *Psalliota campestris B.* and *Polyporus adustus*	–	–	–
2. *Psalliota campsetris B.* and *Lenzites betulina*	–	–	–
VII. *Lycoperdaceae*			
1. *Lycoperdon* sp. (1952 isolate)	–	–	–
2. *Lycoperdon* sp. (1953 isolate)	++	+++	++
B. *Fungi Imperfecti*			
1. *Fusarium conglutinans*	–	–	–
2. *Fusarium vasinfectum strain* f. 1 ..	–	–	–
3. *Fusarium vasinfectum strain* f. 2 ..	–	–	–
4. *Fusarium vasinfectum strain* f. 1 W.Z.R. ..	–	–	–
5. *Fusarium oxysporum strain* f. 2 W.Z.R. ..	–	–	–
6. *Fusarium oxysporum*	–	–	–
7. *Fusarium vasinfectum* (New Delhi) ..	–	–	–
8. *Fusarium vasinfectum* (Poona) ..	–	–	–
9. *Fusarium vasinfectum* (Anand) ..	–	–	–
10. *Fusarium vasinfectum* (Madras) ..	–	–	–
11. *Fusarium vasinfectum* (Calcutta University)	+++	–	–
12. *Fusarium bostrycoides*	–	–	–

TABLE I—*Contd.*

Species of fungi tested	Test organisms		
	Gram-positive	Gram-negative	
	S. aureus	*B. typhosus*	*E. coli*
B. *Fungi Imperfecti*—Contd.			
13. *Helminthosporium sativum*	–	–	–
14. *Helminthosporium demoliatum*.. ..	–	–	–
15. *Helminthosporium oryzae*	+++	+++	++
16. *Helminthosporium oryzae* (sporulating isolate)	+++	+++	++
17. *Helminthosporium oryzae* (non-sporulating isolate)	+	+	+
18. *Alternaria solani*	–	–	–
19. *Alternaria tenuis*	+++	+++	+++
20. *Ctenomyces* sp.	–	–	–
21. *Agaru* fungus (*Torula* sp.)	–	–	–
22. *Phoma casuarinae*	–	–	–
23. „ „ (New Delhi) ..	++	++	++
24. *Actinomyces* sp.	+++	–	–
25. *Sclerotium delphinii*	+++	+++	++

N.B.—Strongly positive = zones 19 mm. and above (+++)
Positive = „ 17 mm. to 19 mm. (++)
Weakly positive = „ 12 mm. to 17 mm. (+)
Negative = (–)

TABLE II

Inhibition-zones produced by twenty-one species of fungi of the 'strongly positive' group against the routine test organisms—S. aureus (*gram-positive*), B. typhosus *and* E. coli (*gram negative*)

Serial no.	Species of fungi	Zones of inhibition (mm.)		
		S. aureus	*B. typhosus*	*E. coli*
1	*Psalliota campestris B.* (1951)	22	22	17
2	*Armillaria mellea*	22	22	18
3	*Lepiota mastoideus*	19	19	18
4	*Daedalea microzona*	25	22	19
5	*Polystictus sanguineus* (monosporous) ..	22	22	17
6	*Lycoperdon* sp.	15	19	15
7	*Fusarium vasinfectum* (Calcutta University) ..	30	15	15
8	*Marasmius campanella*	28	17	17
9	*Polyporus schweinitzii*	21	21	17
10	*Flammula dilepis*	21	21	17
11	*Helminthosporium oryzae*	20	20	15
12	*Lentinus revelatus* (1950)	15	20	20
13	*Lentinus praerigidus* (1950)	15	20	20
14	*Volvaria diplasia*	20	20	19
15	*Alternaria tenuis*	20	20	20
16	*Sclerotium delphinii*	20	20	18
17	*Polyporus gilvus* f. *licnoides* and *Polyporus gilvus* f. *gilvoides*	20	20	18
18	*Polyporus adustus*	21	–	–
19	*Lenzites betulina*	20	–	–
20	*Polyporus anebus*	–	19	–
21	*Ganoderma applanatum*	–	19	–

The crude culture filtrate was found to retain its potency even after two months' storage at room temperature. It was also active at *p*H values ranging from 3·6 to 8·0 (optimum 5·8–6·2). The active substance appeared thermostable, as boiling or autoclaving at 15 lbs. for 10 minutes did not affect its potency. The crude filtrate was active up to a dilution of 1 in 20 and non-toxic to guinea-pigs and white mice. This non-toxicity has also been confirmed by experiments done at the Central Drugs Research Institute, Lucknow. The crude filtrate was also seen to give a certain amount of protection against experimentally induced typhoid in guinea-pigs and white mice.

Attempts were made to get the active substance in a more concentrated form by the solvents extraction process, by adsorption on activated charcoal and Brockmann's alumina and by using ion exchange resins, as also by totally evaporating the crude filtrate and fractionating the residue. Of these, only adsorption on activated carbon ('Darco') proved satisfactory. It was found that by adsorption at *p*H 4, drying the adsorbent, subsequent elution with 80% ethyl alcohol and by evaporation of the eluate at reduced pressure at a temperature of 25°–28°C, a residue could be obtained containing the major portion of the active substance present. By using this method, an extract of the antibiotic was obtained, having approximately eight times the concentration in the crude culture filtrate (*i.e.* in serial dilution test of 1 in 160). The results have been published (Bose, 1953).

As regards solvent extraction process, it was found that while chloroform, ether, ethyl acetate, benzene and petroleum ether were able to extract only a gummy and colourless substance of no activity from the culture filtrate, by using amyl acetate and phosphate buffer *p*H 7 in a three-stage process, extraction of the active substance was equally not found possible.

In order to find out whether the active substance produced by this fungus was also produced intracellularly, aqueous and alcoholic extracts of the mycelial mat, thoroughly dried after removal from the culture medium, were prepared and tested against three test organisms, namely, *S. aureus*, *B. typhosus* and *E. coli.* These extracts, the *p*H of which was in the vicinity of 6·2, were only weakly positive, giving faint zones of inhibition, indicating that the greater part of the active substance was produced extracellularly.

It was also found that, contrary to expectation, aeration achieved by agitation of the culture flasks on horizontal and rotary mechanical shakers, did not improve either growth or antibiotic activity, even when carried on continuously over long periods—up to 150 hrs. Topical application of crude culture filtrate to gynaecological wounds gave encouraging results.

Oral administration of the crude culture filtrate in 2 c.c. ampoule doses supplemented by intramuscular injection of 1 c.c. of the concentrated extract (by the carbon-adsorption process), gave very favourable response in 17 typhoid cases, the fever having been brought down within four days after commencement of the treatment. A short account of 'Antibiotics from Higher Fungi' has been published (Bose, 1952).

Since *Polyporus adustus* was found to have strong antibacterial action against gram-positive *S. aureus*, but no action against gram-negative organisms, attempts were made to combine this activity with that of *Psalliota campestris B.*-filtrate against gram-negative *B. typhosus*, by growing the two fungi together. The results obtained were unsatisfactory.

With the same end in view, *Lenzites betulina* and *Psalliota campestris B.* were grown together and the filtrate tested as usual. The results were again negative.

Tests were also made to see if there was any synergetic antibiotic potency if *Ps. campestris B.* and *Lepiota mastoideus*, (both 'strongly positive' against *B. typhosus*) are grown together in cornsteep flasks. The results were not promising.

The concentrated chemical extract was tried against *Mycobacterium tuberculosis* and *M. phlei*. In both the cases, the results were found encouraging.

Crude extract was obtained from fresh fruit-bodies of *Ps. campestris* bought from the Calcutta Municipal Market, by grinding them in a mortar and extracting with water. The extract (*p*H 6·5), after filtration, was found to possess strong antibiotic action (zones of 22 mm.) against *B. typhosus*. When its *p*H was raised to 7·4 by addition of alkali, the antibacterial activity did not deteriorate. The water extract was found to be non-toxic to guinea-pigs when injected intraperitoneally, and to have Fehling-reducing property. Acetone extract was also obtained in a similar way from fresh fruit-bodies of *Ps. campestris*. It was equally strong in antibacterial activity against *B. typhosus*.

2. *Armillaria mellea.*

The fungus prefers the temperature range of 20°–25°C, growth and activity being very good at this level. It has been taken up for intensive study. In addition to cornsteep, a malt-peptone-glucose broth was also tried and found to be good both for growth and antibiotic activity. It was also found that the crude culture filtrate was non-toxic to guinea-pigs when injected intraperitoneally in 10 c.c. doses at a time.

3. *Lepiota mastoideus.*

This fungus, which was found promising, has been taken up for further study. It is rather exacting in its temperature-requirement, its growth is best between 20° and 25°C like that of *Armillaria mellea*, and very much slower at higher temperatures.

4. *Daedalea microzona.*

Peptone-beef extract-dextrose medium, 3% cornsteep and 0·5% cornsteep liquid medium were tried. Of these, 0·5% cornsteep medium was found to be the best. It was found that about 0·2% of sugar was utilized during the period of growth and antibiotic production.

The filtrate was active at *p*H values ranging from 5·5 to 7·0. Boiling or autoclaving did not affect activity of the culture filtrate; likewise, storage at 28°–30°C for over three months did not impair its potency. Tests showed that the crude filtrate was active in dilutions up to 1 in 40. The filtrate was non-toxic to guinea-pigs and the final *p*H was 6·4.

Attempts were made to extract the active substance by using organic solvents. Of those tried only chloroform proved partially successful.

5. *Polystictus sanguineus* (monosporous).

Several strains of this fungus, including mutants produced by exposure to X-ray and ultraviolet radiation and a monosporous isolate obtained from Dr. S. N. Banerjee of the Calcutta University, were studied in detail. The X-rayed mutant showed slightly greater activity than the normal strain or mutants produced by ultraviolet radiation. But the greatest activity was shown by the monosporous isolate which grew in submerged condition and remained white (non-pigmented).

3% and 0·5% cornsteep, 0·5% linseed extract and 0·5% pea broth, all with 2% glucose, were tried. Though growth was good in all media, antibiotic activity was seen

only in linseed medium and pea broth. Pea broth was the better of the two. Boiling or autoclaving did not affect the activity of the culture filtrates. Activity also remained practically unaffected at *p*H values ranging from 5·5 to 7. Aqueous extract of the mycelial mat showed no antibiotic activity.

Attempts were made to obtain the active substance in a more concentrated form both in this laboratory and at the School of Tropical Medicine (with the help of Dr. R. N. Chakravartty), Calcutta. A certain amount of concentration was achieved by extraction with amyl acetate at *p*H 2·0. All other attempts were unsuccessful.

6. *Lycoperdon* sp. (1953).

In case of 1952 isolate of this fungus a peculiar feature was noticed; the hyphae tended to break up into oidia when grown in cornsteep medium and the *p*H of the medium registered a sharp fall with growth. The antibiotic activity of this isolate was nil. In the 1953 isolate, on the other hand, normal hyphal growth in cornsteep medium was obtained and the antibiotic activity was found to be satisfactory.

7. *Fusarium vasinfectum* (isolate obtained from the Calcutta University).

Several culture media were tried in an effort to find out the best one for growth as well as antibiotic activity. They were: (1) peptone-beef extract-dextrose liquid medium; (2) 0·5% cornsteep liquid and 2% glucose; (3) 3% malt extract and 2% glucose; (4) 3% cornsteep liquid without glucose, and with 1·5%, 2% and 4% glucose. It was found that only in 3% cornsteep liquid medium with 2–4% glucose, growth and antibiotic activity were satisfactory. The utilization of sugar in the medium for antibiotic production was found to be only 0·5%. The *p*H value of the medium rose up to nearly 8 from a starting level of 6·0, during the peak period. Dilution-tests with crude culture filtrate showed no growth up to a dilution of 1 : 40. The mycelial mat, dried and extracted with water, yielded an active extract. Besides being strongly positive against *S. aureus* (the routine gram-positive test organism), this was also strongly positive against two other gram-positive organisms, *Streptococcus haemolyticus* and *Bacillus subtilis*. On the gram-negative side, besides the routine test-organisms *B. coli* and *B. typhosus* it was weakly positive also against *B. proteus* and *B. pyocyaneus*. Inoculation experiments showed that the crude culture filtrate was non-toxic to guinea-pigs and white mice. Applied locally and injected intramuscularly in cases of osteomyelitis, it was found to give very encouraging results. The active substance was thermostable. The potency of the crude filtrate remained unimpaired by boiling or autoclaving at 15 lbs. for 20 minutes.

8. *Marasmius campanella*.

Isolates of this fungus from the bark of the trunk of the living tree of *Lagerostræmia flos-reginae* made in different years did not show the same degree of antibiotic potency. For instance, 1949 and 1950 isolates were uniformly negative while isolates made in 1951 and 1952 from the same tree were positive against both gram-positive and gram-negative bacteria, but its main potency was against *Staphylococcus aureus* though some degree of antibiotic potency was to be found against *B. typhosus* from time to time. This shows how *Marasmius campanella* is variable in its antibiotic activity. Conditions leading to this variability in antibiotic activity are obscure; in this connection Wilkins and Partridge's (1950) remarks that 'the antibacterial activity is, in fact, a function of the individual rather than of the species' may be cited for similar behaviour. The crude

culture filtrate was non-toxic to guinea-pigs on injection. The variability in its potency can be fixed by appropriate chemical treatment.

Attempts to vary cultural conditions by supplementing the cultural medium (0·5% cornsteep + 2% glucose) with small doses of salts like $ZnSO_4$ and by growing on a natural medium, namely leaf extract of *Adhatoda vasica*, proved unsuccessful. It was also noted that there seemed to be two distinct active fractions, one highly thermolabile and the other only moderately so. The former could be extracted with ether. The activity of the ether extract was preserved only for a very short time, *i.e.* 10–12 hours at 25°–30°C. Storage at cooler temperature showed a slight improvement, activity being maintained for a longer time, but there was a gradual decline in activity during storage even at temperature of 4°-5°C. At this temperature its activity slowly declined day by day and was totally lost in five to six days.

9. *Polyporus schweinitzii.*

Investigations on this fungus were confined to the winter months of the year (room temperature of 22°–26°C) when temperature conditions were favourable for it. 0·5% cornsteep with 2% glucose and salts was found to be the best. The addition of vitamin B_1 to the medium had a slight accelerating effect on growth and antibiotic activity. It was found that carbohydrate consumption during growth and antibiotic production was about 0·2%.

Oral administration of the crude culture-filtrate supplemented by injection of the material concentrated by elution of charcoal adsorbent, gave inconclusive results in typhoid and *B. coli* cases in our Hospital.

10. *Flammula dilepis.*

0·5% cornsteep and whey liquid media were found to be equally good for growth and antibiotic activity. The final *p*H of the media ranged from 5·2 to 5·8. Animal experiment showed the filtrate to be non-toxic.

The culture filtrate also exhibited *antifungal activity* (against *Pythium* and *Phytophthora*) in addition to antibacterial activity.

11. *Helminthosporium oryzae.*

Addition of 20 μg. of vitamin B_1 to the 0·5% cornsteep medium was found essential for good growth and activity. It was noticed that antibiotic activity was of short duration.

12. *Lentinus revelatus* (1950).

Peptone-beef extract-dextrose medium, 3% cornsteep, 0·5% cornsteep with 2% and 4% glucose and with or without sodium citrate were tried in this case. Growth and activity were found to be the best on 0·5% cornsteep with 2% glucose. The amount of sugar utilized during antibiotic production was 0·3%. The culture filtrate was active at *p*H 5–7; and dilution tests showed its activity up to 1 in 20.

The culture filtrate remained unimpaired in potency after being kept for two months at room temperature. Boiling did not destroy its activity; the active substance is consequently thermostable. It was non-toxic to guinea-pigs.

Besides the routine test organisms, *S. aureus*, *B. typhosus* and *E. coli* it was also strongly positive against *Streptococcus haemolyticus*.

13. *Lentinus praerigidus* (1950).

Peptone-beef extract-dextrose medium, 3% cornsteep and 0·5% cornsteep with 2% glucose and with or without sodium citrate were tried. Growth and activity were best in 0·5% cornsteep with 2% glucose. The culture filtrate remained active at *p*H ranging from 5 to 7.

14. *Volvaria diplasia*.

Growth and antibiotic activity were found to be equally good in both 0·5% cornsteep and pea broth. The culture filtrate remained active at *p*H ranging from 3·6 to 7·0. Tests showed that the crude filtrate was active in dilutions up to 1 in 20 against the test organisms.

15. *Alternaria tenuis*.

3% malt and 0·5% cornsteep were both tried; though growth was good in both, activity was seen only in 0·5% cornsteep. The antibiotic activity was of short duration.

16. *Sclerotium delphinii*.

Growth and activity were studied in 0·5% cornsteep. It was found that the *p*H of the medium was reduced to a remarkable extent within a short period, coming down to about 2 0. All available sugar in the medium was completely used up within one month. Attempts were made, both in this laboratory and by Dr. R. N. Chakravartty at the School of Tropical Medicine, Calcutta, to extract the active substance in organic solvents, but they were without success. The zones of inhibition were suspected to be due to high acid factor (*p*H 2).

17. *Polyporus gilvus f. licnoides* and *Polyporus gilvus f. gilvoides*.

An interesting feature noticed in the case of these two species was that during the first two weeks of growth, the *p*H of the medium was lowered only to a slight extent and antibiotic activity was fair. After this, however, aerial mycelium made its appearance and there was a rapid fall in the *p*H of the culture substrate, accompanied by marked decline in antibiotic activity.

18. *Polyporus adustus*.

It has got some antibiotic action against gram-positive organisms only, such as *S. aureus*.

19. *Lenzites betulina*.

It has also got an action similar to *Polyporus adustus* but it is less active.

20. *Polyporus anebus*.

It has good antibiotic potency against *B. typhosus* only but the *p*H value comes down to 5·1 soon from 6·2.

21. *Ganoderma applanatum*.

It has also strong antibiotic action against *B. typhosus*. The *p*H does not appreciably fall.

REMARKS

From the summarized results it tentatively follows that though utilization of sugar during growth was not much, glucose helps greatly in production of antibiotic activity. This antibiotic activity is greatly determined by the nature of the culture medium and the particular strain of the fungus employed. It is our experience that usually greater growth is not rewarded by greater antibacterial activity; in this connection Robbins' (1953) experience is also the same. These questions have been fully discussed in a previous paper (Bose, 1953).

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XIII. ON THE CHOICE AND DESIGN OF REACTORS *

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§1. Introduction

As is generally known, the reactor is the atomic furnace. It is a device based on two scientific discoveries, *viz.*—

(*a*) Fission of certain heavy nuclei, *viz.* U^{235} which occurs naturally, and Pu^{239} and Th^{233} which have been made in the laboratory; and

(*b*) The principle of chain-reaction.

It is assumed that these principles are known and no attempt has been made to describe them.

Immediately after the discovery of fission, scientists of many countries realized that the discovery had pointed out to a source of energy, which had much greater potentiality than energy obtained from combustion, which was so long the mainstay of industries and transport. Scientists of many countries began to think simultaneously how this energy could be made available for useful work, and many people simultaneously thought of chain-reaction.

But the first reactor which embodied the principles (*a*) and (*b*) was completed in Chicago in the year 1942 under the direction of E. Fermi and was a graphite-moderated natural uranium reactor. The success achieved encouraged the U.S.A. Government to build during the war the Oak Ridge reactor and the Handford production reactors, which yielded plutonium used for making the first atom-bombs. After the termination of the war, the U.S.A. Government organized a huge programme on atomic energy development including construction of different types of reactors. But they excluded even friendly nations like U.K. and France from active participation in the work, and by the MacMahon Act of 1946 put a ban on the export of all atomic knowledge and equipment, unless they were declassified. But nothing undeterred, Soviet Russia, England and France started their own atomic energy work, and by 1950 had achieved signal success in the construction of reactors. By 1952, even Norway and Holland were able to construct successfully heavy-water reactors, out of their own resources.

By 1950, U.S.A. (which in the present context also includes Canada) realized that the atomic monopoly sought by it was broken and that it was useless to keep back the knowledge which other nations had obtained by their own efforts and certain amount of information on the design and working of reactors was declassified.

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* This is a report submitted to the conference on Atomic Energy Development held at New Delhi on November 25 and 26, 1954. Generally, such a report has to be compiled by a person who has worked on the subject, and has acquired experience and knowledge. But the reporter regrets that along with other participants of this conference, he has no experience in the handling of a reactor, because India has as yet no reactor, and no Indian, to his knowledge, has any experience of actually handling a reactor. All the information given here is derived from book-knowledge, or from knowledge obtained in course of the reporter's visits to atomic energy establishments in foreign countries. Further, it is well-known that much knowledge is still withheld by U.S.A., U.S.S.R., and other countries. Any discussion on reactors is, therefore, bound to be rather incomplete.

Before proceeding further, let me give you diagrammatically, an idea of the different types of reactors. This is done in Tables I to VII.

In these tables, the reactors are classified according to moderators, and nuclear fuel used. The moderators are graphite, beryllium, heavy water or ordinary water, and there are reactors with no moderator at all. The fuel used may be natural uranium (99·3% U^{238}, 0·7% U^{235}), enriched uranium (*i.e.*, uranium in which the proportion of the active component U^{235} is increased by artificial methods) or 100% U^{235}, Pu^{239} or Th^{233}.

§2. Other methods of classification

The reactors are also classified according to their mode of action as slow or thermal, intermediate, or fast. The slow or thermal reactors are those in which the neutrons released are moderated to thermal energy by collision with moderator-nuclei. Their action depends on the fact that it is only the slow thermal neutrons which cause effective fission of U^{235}. Not much is known of the working of intermediate or fast reactors in which moderation is more or less discarded; they use enriched uranium or pure fissile material. Information on these reactors have not been allowed to be declassified.

Reactors are also classified, according to the purpose for which they are made, as follows:

(*a*) General purpose reactors,
(*b*) Production reactors,
(*c*) Breeder reactors,
(*d*) Research reactors,
(*e*) Power reactors.

Combination of more than one purpose is possible in a reactor.

The early reactors, graphite-natural uranium, or heavy-water-natural uranium, were used for general purpose, *viz.*, for research on design of reactors, for the production of radio-isotopes either from fission or exposure to streams of neutrons. The Oak Ridge graphite-moderated reactor, built in 1943, is still used for the making of radioactive isotopes. The Hanford reactors were used for the production of plutonium which made up one of the atom-bombs dropped on Japan.

Necessity of Breeding.

Of the two isotopes of U, only U^{235} occurring in the proportion of 1 : 140, is active. But for the existence of U^{235} in Nature, there would have been no *atomic energy development* for an unpredicted number of years as the great investigator Lord Rutherford held, up to the time of his death (1937). But the proportion of U^{235} in uranium in the world is so small that unless we can find a substitute there can be no satisfactory atomic power development to serve the needs of the world for a sufficiently long period of human history. Hence, it is imperative that we replace U^{235} as fast as it is consumed by other fissile material. But no other fissile nuclei have yet been found in Nature; they have to be made artificially in the laboratory. A new fissile material Pu^{239} is formed in reactors when the more abundant nucleus U^{238} captures a neutron. When the element thorium (Th^{232}) which occurs more plentifully than U in nature captures neutrons, it leads to the formation of U^{233}, which is a third fissile material. The object has, therefore, been to devise new types of reactors called *Breeder Reactors*, in which more Pu^{239} or U^{233} is produced than U^{235} is consumed. Such reactors can be used for the conversion of U^{238} to Pu^{239} or Th^{232} to U^{233} on a large scale. The great Hanford reactors constructed in the

TABLE 1

Natural Uranium—Graphite Reactors

Reactor	Location	Year of operation	Composition (in tons)	Power in kW.	Power (kW.) Fuel (tons)	Neutron flux	Cost (in million dollars)	Remarks	Source reference
CP–1 ..	Argonne, U.S.A.	1942	6 U, 40 U_3O_8 385 C	0·1	2×10^{-3}	4×10^{6}	1·5	Thermal, Hetero.	*Nucleonics*, April, 1954
CP–2 ..	Argonne, U.S.A.	1943	10 U, 42 U_3O_8 472 C	2	4×10^{-2}	1×10^{8}	2·0	,,	,,
X–10 ..	Oak Ridge, U.S.A.	1943	85 U, 620 C	3,800	110	5×10^{11}	5·2	,,	,,
U^{238}—Production reactors	Hanford, U.S.A.	1945	..	$\approx10^{6}$	..	..	..	(*a*) ,, (*b*) At least 4 are in operation	(*a*) Stephenson: *Nuclear Engineering* (p. 68). (*b*) *Nucleonics*. Dec., 1954 (p. 70).
GLEEP ..	Harwell, U.K.	1947	12 U, 21 U_3O_8 505 C	100	3	3×10^{10}	..	Thermal, Hetero.	(*a*) Lenihan: *Atomic Energy* (p. 126). (*b*) *Harwell* (p. 95).
BEPO ..	Harwell, U.K.	1949	40 U, 850 C	6,000	150	1×10^{12}	..	Thermal, Hetero.	Lenihan: *ibid.*, p. 101.
BNL ..	Brookhaven, U.S.A.	1950	60 U, 700 C	28,000	470	2×10^{12}	20·0	,,	*Nucleonics*, April, 1954.
Windscale reactors	Windscale, U.K.	1950	Several thousand tons of U & graphite (C)	..	..	..	..	(*a*) ,, (*b*) Two in operation	Jay: *Britain's Atomic Factories* (p. 27).
Cumberland power reactor	Cumberland, U.K.	1955	..	40,000 kW. (of electricity)	..	..	..	Thermal, Hetero.	*Nucleonics*, June, 1953 (p. 86); Jany., 1954 (p. 7).

The first reactor in the world CP–1 was ___de at Chicago in 1' It was graphite-moderated.
The other graphite-moderated reactors made in the different countries are shown in the chart wi uel, neutron flux and costs.
The chart shows the enormous improvement in performance of this type of reactors with tim ch is used for research. The X–10 at Oak Ridge is now mostly used for production of isotopes.
Besides U.S.A., the U.K. is the only country which has constructed graphite-moderated reac PO is being used for research and production of isotopes. The British and French are constructi ver. Sir John Cockcroft estimates the cost of pow duction to be 1*d*. per kWh.

er, pc

CP–1

TABLI

Natural Uranium—H y-water Reactors

Reactor	Location	Year of operation	Composition (in tons)	Power in kW.	Power (kW.) / Fuel (tons)	Neutron flux	Cost (in million dollars)	Remarks	Source reference
CP-3 ..	Argonne, U.S.A.	1944	3 U, 6·5 D_2O	300	100	5×10^{11}	2·0	(*a*) Originally built for research purposes. (*b*) Thermal, Hetero.	*Nucleonics*, April, 1954.
NRX ..	Chalk River, Canada.	1947	10 U, 17 D_2O	30,000	3,000	2×10^{13}	10	,,	,,
ZOE ..	Chatillon, France.	1948	3·6 UO_2, 6 D_2O	10	3	2×10^{10}	..	,,	(*a*) Lenihan: *ibid.* (p. 126). (*b*) *Physics Today*, Jan., 1951.
JEEP ..	Kjeller, Norway.	1951	2 U, 7 D_2O	300	150	1×10^{12}	..	,,	Kjeller Conference on Heavy-Water Reactors (1954).
P-2 ..	Saclay, France.	1952	3 U, 7 D_2O	1,200	360	4×10^{12}	..	(*a*) Originally built for research purposes. (*b*) Thermal, Hetero.	(*a*) Booklet on 'Saclay'. (*b*) *Les Atomes*, April, 1953, p. 114. (*c*) Kjeller Conference Report. (*d*) *Nucleonics*, Sept., 1954.
SLEEP ..	Stockholm, Sweden.	1954	U, D_2O	300	..	..	..	Like JEEP or CP-3.	(*a*) Kjeller Conference Report. (*b*) *Nature*, **174**, 161, 1954.

TA [illegible] —*Co*[illegible]*td.*

Reactor	Location	Year of operation	Composition (in tons)	Power in kW.	Power (kW.) / Fuel (tons)	Neutron flux	Cost (in million dollars)	Remarks	Source reference
U^{235} Production reactor	Savannah River, U.S.A.	1954(?)	..	..	..	..	..	(*a*) Primarily used for producing materials for A or H-bombs. (*b*) Usable power produced.	Gordon Dean: ***Report on the Atom*** (p. 136–46).
NRU ..	Chalk River, Canada.	1955	..	..	..	..	..	..	*Nucleonics*, Feb., 1953.
Swiss reactor ..	Switzerland.	..	5 U, 11 D_2O	10,000	2,000	2×10^{13}	10	At present in the design stage.	Kjeller Conference Report.

The first heavy-water moderated reactor CP–3 was made at Chicago in 1944.

These reactors require about $\frac{1}{5}$ to $\frac{1}{10}$th the amount of uranium required for graphite-moderated reactors, but what is gained in uranium is lost in the price of heavy-water which costs \$200 per kg. and $2 \cdot 10^5$ dollars per ton. These reactors are less bulky, easier to construct and control but rather complicated devices have to be made for the recovery of precious D_2O.

According to expert opinion, the heavy-water moderated reactors have not much of future unless the price of heavy-water, the supply of which is at present the monopoly of a single nation (Norway) can be brought down. Researches are in progress for discovery of newer methods of production of D_2O which will bring down the costs. The amount of fuel to be used is reduced drastically when the fuel is enriched.

TABL

Enriched Uran… 'or Graphite and Heavy-water Moderators

Reactor	Location	Year of operation	Composition (in tons)	Power in kW.	Power (kW.) Fuel (tons)	Neutron flux	Cost (in million dollars)	Remarks	Source reference
North American Aviation's homogeneous graphite reactor	Downey and Livermore, U.S.A.	..	3·2 kg. U_3O_8	160	40,000	1×10^{12}	1·4	(*a*) Thermal, Homo. (*b*) At present in the design stage.	*Nucleonics*, April, 1954.
Sodium reactor experiment (SRE).	Santa Susana, U.S.A.	1956	Slightly enriched U or U^{233}+Th.	20,000	..	..	10	..	U.S A.E.C.'s 16th Semi-Annual Report.
CP-3' ..	Argonne National Laboratory, Chicago, U.S.A.	1950	1·2 kg. U+Al 6·5 D_2O	300	68,000	2×10^{12}	2	Thermal, Hetero.	*Nucleonics*, April, 1954.
CP-5 ..	Argonne National Laboratory, Chicago, U.S.A.	1953	4 kg. U+Al 7 D_2O	1,000	910,000	2×10^{13}	3	,,	*Nucleonics*, April, 1954.
DIMPLE ..	Harwell, U.K.	1954	Highly enriched uranium.	Low power	..	..	..	(*a*) Thermal (*b*) Used as a research reactor.	*Nature*, Vol. 173, p. 852; also, Vol. 174, p. 251.

The homogeneous graphite-moderated enriched uranium reactor whicl is been located at the atomic energy laboratory of the North Ameri ition Inc., of Downey, California, U.S.A., is a new and pror ising departure. Enriched U and graphite are put together as a homogeneous mixture The fuel will have to be reprocessed after 10 years (at 10^{12}/cm.^{2} sec. neutron flux for 2,(0 hrs. per year). It uses 3·2 kg. of ($U_3{}^{235}C_8$). It uses, as pri D_2O, and as secondary, H_2O. The reflector is of graphite and the shield is made of eel and concrete (450 tons). As a next step, the North Inc. are trying to develop the sodium-graphite reactor (SRE) for power production.

The first two are graph e moderated and the re are heavy-water mode

TABLE IV

Enriched Uranium—Light Water Reactors:

A. *Boiling-water Types*

Reactor	Location	Year of operation	Composition (in tons)	Power in kW.	Power (kW.) Fuel (tons)	Neutron flux	Cost (in million dollars)	Remarks	Source reference
LOPO ..	Los Alamos, U.S.A.	1944	0·5 kg., UO_2SO_4 (15%)	$<1\times10^{-8}$	..	..	..	Thermal, Homo.	*Nucleonics*, April, 1954, (p. 13).
HYPO ..	Los Alamos, U.S.A.	1944	0·8 kg., UO_2SO_4 (15%)	6	7,000	1×10^{11}	0·5	Thermal, Homo.	,,
SUPO ..	Los Alamos, U.S.A.	1951	0 8 kg., UO_2SO_4 (88·7%)	45	50,000	1×10^{12}	0·5	Thermal, Homo.	,,
NCSR (North Carolina State College water boiler.)	Raleigh, North Carolina, U.S.A.	1953	1 kg., UO_2SO_4 (80%)	50 (maxm.)	45,000 (maxm.)	$2·5\times10^{12}$	0·5	(*a*) Thermal, Homo. (*b*) First university built reactor.	,,

The percentages indicated in column 4 represent the enrichment factor of U^{235}.

B. *Swimming-Pool Types.*

Reactor	Location	Year of operation	Composition (in tons)	Power in kW.	Power (kW.) Fuel (tons)	Neutron flux	Cost (in million dollars)	Remarks	Source reference
Low Intensity Tesi Reactor (LITR).	Oak Rid U.S.A.		3 kg., U (90%)	2,(					*Vucleon* 954, (p. 12-1
Bulk Shieldin Facility (BSF).	Oak Rid U.S.A.		— — 2·5 kg.	00					
Material Testing Reactor (MTR).	..., U.S.A.		4 kg.	30,					
S[illegible] ıarine The[illegible]- Reactor No. 1 ıd-based proto- ;, STR—1).	Arco, U.S.A.								(*a*) Gordon Dean: *Report on the Atom* (p. 136–146). *Nucleonics*, May, 1953.

TABLE IV

Enriched Uranium—Light Water Reactors—Contd.

B. *Swimming-pool Types*

Reactor	Location	Year of operation	Composition (in tons)	Power in kW.	Power (kW.) Fuel (tons)	Neutron flux	Cost (in million dollars)	Remarks	Source reference
ORR ..	U.S.A. ..	1956	2·5 kg. U	5,000	1,800,000	5×10^{13}	2·8	Conceptual design of a reactor of the MTR Type; *does not refer to a specific reactor project.*	*Nucleonics*, April, 1954, (p. 13).
Experimental Boiling Water Reactor (EBWR).	Arco, Idaho, U.S.A.	1956	Natural U+ enriched U^{235}	20,000	..	..	17·0	At present in the design stage.	U.S.A.E.C.'s 16th Semi-Annual Report.
Pressurized Water Reactor (PWR).	Shipping-port, Pa., U.S.A.	1957	15–20 U (concentration of U^{235} is 1·5—2%).	300,000	..	..	85·0	(*a*) At present in the design stage. (*b*) To be used as a power reactor	U.S.A.E.C.'s 16th Semi-Annual Report.
Submarine Thermal Reactor No. 2 (STR—2).	U.S.S. *Nautilus* U.S.A.	..	..	..	..	..	..	At present in the design stage.	*Nucleonics*, Sept., 1954, (p. 66).

These reactors have been evolved entirely in the U.S.A. They all use enriched uranium. There are two main types, *e.g.* 'Water-Boiler' and 'Swimming Pool'.

The Water-Boiler Type: We first describe the water-boiler type, the first of which (LOPO) was made at Los Alamos in 1944. Subsequently two others were made there, the HYPO (1944) and the SUPO (1951). They use enriched uranium in the form of solutions of uranium sulphate in light water or as a slurry. The details of water-boiler types of reactors have been published in various issues of *Nucleonics*. The low-power water-boiler reactor is one of the most suitable type which can be installed in a research institute or a university, specially because of its low cost. North Carolina State College in America has installed such a reactor in its campus—the first reactor to be installed in a university.

The Swimming-Pool Type: It is an enriched uranium water-moderated, water-cooled, thermal reactor. The cost of installation of a low-power reactor of this type is the lowest. Hence they are also very suitable as university reactors. Many American universities are planning to instal one of the above two types of reactor. Fuel will be supplied by the U.S.A.E.C.

TABLE V

Enriched Uranium—Beryllium Reactors

Reactor	Location	Year of operation	Composition (in tons)	Power in kW.	Power (kW.) / Fuel (tons)	Neutron flux	Cost (in million dollars)	Remarks	Source reference
Submarine Intermediate Reactor—A (SIR—A) (land-based).	West Milton, N.Y., U.S.A.	..	..	..	..	..	..	Under construction now.	(*a*) Gordon Dean: *Report on the Atom* (p. 136–46). (*b*) *Nucleonics*, Sept., 1954.

Only one reactor of this type has so far been designed. It will work with neutrons of intermediate energy.

TABLE VI

No-Moderator: Fast Reactors

A. *Enriched Uranium*

Reactor	Location	Year of operation	Composition (in tons)	Power in kW.	Power (kW.) / Fuel (tons)	Neutron flux	Cost (in million dollars)	Remarks	Source reference
Experimental Breeder Reactor No. 1 (EBR—1)	Arco, Idaho, U.S.A.	1951	Pure U^{235}	1,400	..	$6{\cdot}5\times10^{14}$	3 0	(*a*) Fast (*b*) To be used for development of power and breeding.	(*a*) *Nucleonics*, Sept., 1952 (p. 8). (*b*) 16th Semi-Annual Report, U.S.A.E.C.
Experimental Breeder Reactor No. 2 (EBR—2)	Arco, Idaho, U.S.A.	1958	At first U^{235}, Later on Pu^{239}	62,500	..	..	40(?)	(*a*) Fast power reactor. (*b*) At present in the design stage.	U.S.A.E.C.'s 16th Semi-Annual Report.

B. *Pure Plutonium.*

Reactor	Location	Year of operation	Composition (in tons)	Power in kW.	Power (kW.) / Fuel (tons)	Neutron flux	Cost (in million dollars)	Remarks	Source reference
CLEMENTINE ..	Los Alamos, U.S.A.	1946	..	10	..	5×10^{12}	..	Fast, Hetero.	(*a*) Gordon Dean: *Report on the Atom* (p. 136–46). (*b*) Stephenson: *Nuclear Engineering*.
ZEPHYR ..	Harwell, U.K.	1954	..	Zero power	..	..	..	(*a*) Fast (*b*) To be used in expts. on breeding.	*Atomic Scientists Journal*, p. 273, (1954).

No moderator: These reactors use pure fuel, either pure U^{235} or Pu^{239}. They have very small size. The fuel is in the form of lumps separated from one another, so that no explosion may occur. They work with fast neutrons. They are used as cores in breeder reactors in which the synthetic fissionable materials Pu^{239} or U^{233} are produced from U^{238} and Th^{232} respectively by neutron capture. At least as much synthetic fuel is produced in a breeder as the amount of fuel consumed.

TABLE I

Types

Reactor	Location	Year of operation	Composition (in tons)	Power in kW.	Power (kW.) Fuel (tons)	Neutron flux	Cost (in million dollars)	Remarks	Source reference
Homogeneous Reactor Expt. No. 1 (HRE—1).	Oak Ridge, U.S.A.	1952	Enriched U	1,000	..	..	1·0	(*a*) Water-boiler type. (*b*) Liquid moderator. (*c*) Thermal, Homo. (*d*) Used for the study of power possibility.	Murray: *Nuclear Engineering* (p. 102).
Homogeneous Reactor Expt. No. 2 (HRE—2).	Oak Ridge, U.S.A.	1956	Enriched U	5,000	..	..	47·0(?)	(*a*) Water-boiler type. (*b*) To be used for power study.	U.S.A.E.C.'s 16th Semi-Annual Report.
British Breeder Power Reactor.	Northern Scotland.	1956	.	50,000 kW. (of electricity).	..	..	..	..	*Nucleonics*, Dec., 1953, p. 70.
Homogeneous Thorium Reactor (HTR).	Oak Ridge, U.S.A.	1959	At first, probably U^{235}, later on U^{233}.	65,000	..	..	44·0	At present in the design stage.	(*a*) U.S.A.E.C.'s 16th Semi-Annual Report. (*b*) *Nucleonics*, Sept., 1954, p. 66.
Boiling Experiments.	Arco, Idaho, U.S.A.	..	..	..	..	..	..	Two reactors.	(*a*) U.S.A.E.C.'s 16th Semi-Annual Report. (*b*) *Nucleonics*, Sept., 1954, p. 66.
E 443 ..	U.K.	..	..	..	..	..	..	At present in the design stage.	"
Submarine Intermediate Reactor —B (SIR—B).	U.S.S. *Sea Wolf* U.S.A.	..	..	..	..	..	..	At present in the design stage.	*Nucleonics*, Sept., 1954.

U.S.A. during the war, or the British reactors erected at Windscale in 1950 for the production of Pu^{239} should not be called 'Breeders', for they consume larger number of U^{235}-atoms than the number of Pu^{239}-atoms they produce. These reactors produce from 80% to 90% Pu^{239}.

The U.S.A. announced in 1953, the successful operation of a breeder reactor at the Physical Laboratory at Idaho under the direction of Zinn (*Nucleonics*, Nov., 1953, p. 30). The details have not yet been declassified. It is probably a fast reactor without the use of moderators and uses an assembly of Pu^{239}-lumps of subcritical size for the production of an intense source of neutrons.

§3. General principles of reactor construction and control

The working of the reactor depends on the 'sustenance' of the 'chain-reaction'. Suppose we have a neutron causing fission of a U^{235}-nucleus occurring in the reactor. This gives rise on the average to 2·5 fast neutrons. What happens to these as they pass through the matrix of the reactor?

Some of these are captured by U and the moderator material. Others are scattered by the nuclei of moderators and of fuels. Some escape capture before being slowed down, and a fraction is absorbed in the fuel. Others leak out of the reactor. The possible fates of the neutrons are listed in what is called the neutron balance sheet. After all these vicissitude, we get K slow neutrons capable of producing further fission. If $K \gg 1$, the chain-reaction is sustained, otherwise it stops. It has been shown that K depends on five factors:

$$K = \eta \epsilon p f F$$

This is known as the five-factor formula. Let us explain the significance of each term on the right-hand side.

The last factor F is due to leakage from the reactor. If the reactor were of infinite size, there would be no leakage. But as in actual practice it is of finite size, F is < 1. But reactors are surrounded by a mantle of graphite or beryllium, which reflect most of the leaking neutrons back to the reactor. It is, therefore, the general custom to make calculations with an infinite reactor, *i.e.*, with $F = 1$.

Let us now take the other factors one by one.

η = average number of fast neutrons emitted as a result of the capture of the primary thermal neutron by the fuel.

If we had pure U^{235} as fuel $\eta = 2{\cdot}1$ and not 2·5, for not all thermal neutrons captured by U^{235} cause fission, but only a fraction given by $\sigma_f/\sigma_f+\sigma_c$

where σ_f = fission cross section; σ_c = capture cross section of U^{235} producing U^{236}.

So that
$$\eta = \nu \cdot \frac{\sigma_f}{\sigma_f+\sigma_c}$$

If it is natural uranium, we have to consider the action of the slow neutron on U^{238}. This further brings down η to 1·32. For enriched uranium, η varies between 1·32 and 2·1, becoming larger as the enrichment becomes larger.

The calculation of η is a very important item in 'Reactor Technology'. Actually it is not so simple as given above, for σ_{fission} and σ_{cap} depend on the velocity of neutrons. The full data do not seem to have been declassified.

The second factor ϵ is known as the fast fission factor, for fast neutrons also cause fission, though to a slighter extent than slow ones. ϵ is the ratio of total number of fast

neutrons produced by fissions due to neutrons of all (fast and slow) energies to the number resulting from thermal neutron fissions.

For graphite and U reactor, ϵ is taken to be 1·03. Both η and ϵ depend on the fuel-material.

p = Resonance escape probability

= Fraction of fast (fission) neutrons that escape resonance capture, mostly in U^{238}, while being slowed down. For the British reactor BEPO, $p = 0{\cdot}899$.

f = Thermal utilization factor

= Ratio of thermal neutrons absorbed in the fuel leading to fission to the total number of thermal neutrons absorbed by fuel, moderator and other materials and not leading to fission. For BEPO, $f = 0{\cdot}889$

p and f can be varied to some extent. They are both less than unity, but for chain-reaction to proceed, should be as large as possible. Unfortunately, such changes in the relative proportion of fuel and moderator which increase p decrease f. For instance, reducing the amount of moderator increases f, but the greater relative proportion of U^{238} decreases p, and *vice versa*. The optimum arrangement should give the maximum value of the product pf.

The exact calculation of the quantities η, ϵ, p, f depends upon experimental data involving variation of different kinds of nuclear cross sections with velocity of neutrons and on the nuclear properties of reactor materials. Most of these are still classified material. Even when these fundamental data are available, the best working conditions will depend on the design selected, for which the values of η, ϵ, p and f have separately to be calculated theoretically and verified experimentally. These involve mathematical and experimental skill of the highest order.

But when the idea of the reactor was first mooted, the values of the quantities η, ϵ, p and f were only roughly calculated, and due to the urgency of the military situation, work on reactors started without stopping for further refinement. The early reactor work was done rather '*brutally*'.

After the termination of the war, greater attention is being paid to the determination of the four factors determining K, both theoretically and experimentally. The student of reactor technology will find an excellent summary of the declassified material in the *Elements of Nuclear Reactor Theory*, by Glasstone and Edlund, written under instructions from the Atomic Energy Commission of U.S.A. There are schools of 'Reactor Technology' at Oak Ridge, U.S.A., and Harwell, England, where instructions are given to students on reactor physics and technology. We should have such a school in India, for the last word on the design of reactors has yet to be said, and probably better knowledge of fundamental quantities and better design may save millions of dollars and develop and extend the fundamental knowledge of this science.

The published literature is confined only to the treatment of thermal reactors. The great amount of work, going on in the U.S.A. on intermediate and fast reactors which are expected to solve the problem of production of *economic* electrical power from nuclear energy and details of successful breeder reactors are still classified. Probably these will not be made public before other countries embark on similar enterprises.

§4. Need for growth of scholarly tradition

The absence of scholarly tradition is to be very much regretted and in a recent issue of *Nucleonics*, Dr. A. Weinberg, Technical Director of the Oak Ridge National Labora-

tory, pleads for the growth of a scholarly tradition in nuclear development. He says (*Nucleonics*, Sept., 1954, p. 20):

> 'Although American work in nuclear energy now proceeds on a colossal scale, we still believe that there is a need and place for the pursuit of technology on a smaller, more leisurely and more scholarly basis than it is pursued here.'

The European countries, unable individually to cope with America in money or organization, have combined to put up a Centre Europeen pour la Recherche Nucleaire shortly called C.E.R.N. for the pursuit of fundamental researches in nuclear science. The laboratory will spend much less than a single American atomic national laboratory, but that does not mean the intellectual output will be less. Says Dr. Weinberg:

'Of the commodities necessary for establishing and nurturing the scholarly tradition, I would place money *a poor third to time and brains.*'

§5. What kind of reactor India should have

In India, the greatest handicap to the development of nuclear energy is, first of all lack of a proper organization which is dealt with elsewhere. Even the few laboratories which have started work on this line are handicapped by the absence of a reactor, for this provides a source of neutrons of the order of 10^{12} to 10^{14} per $cm.^2$ per sec., which is indispensable for the persuit of many researches on nuclear energy. It is understood that plans are being made to obtain a heavy-water moderated natural uranium reactor for our A.E.C., but this point should be very carefully deliberated. The heavy-water moderated reactor certainly requires far less uranium, about 1/10th of the amount for a graphite moderated reactor, as shown in Table II, but it is not realized that what we gain in the price for lesser quantity of uranium to be used, is more than made up by the price of the heavy-water needed for the purpose. America may build heavy-water reactors for they have unlimited funds, or Norway may build it for it is the only country which makes heavy-water, and their own costs of production must be much less than those at which they sell this commodity to other countries, as they are virtually monopolists. But as long as we have to purchase heavy-water from Norway, the proposition will remain a very expensive one.

In fact in the Kjeller Conference on Heavy-Water Reactor, the British representative, Mr. Dunworth remarked:

'I think I can say that we (British) shall not actually build the plants unless heavy-water is produced *much more cheaply than at present*, or at least, it is not very likely.'

Recently, it has been announced that the British Government, in co-operation with the New Zealand Government, is going to set up a plant in New Zealand, where heavy-water is expected to be produced far more cheaply.

The British representative was not alone in his views. Dr. Kowarski, the inventor of the idea of heavy-water reactor, said:

'On the whole I think, however, that in spite of all those advantages, the time of heavy-water reactor for laboratory use is drawing to a close.'

The present price of heavy-water is $87 per pound. To what extent is the price to be reduced if heavy-water reactors are to be economic? This is revealed in a remark by Dr. Weinberg:

'I should like to say again that nothing that I have said or that any of other gentleman said should be construed to contradict your (Dunworth's) very well taken point that heavy-water is too expensive and in fact, I have not been authorized to say so, but I think

that the United States will buy as much heavy-water as anybody can produce if he will sell it at 5 dollars per pound.'

It has been remarked that heavy-water may be produced as a by-product of the fertilizer plant to be set up at Bhakra-Nangal and we shall get heavy-water *at no price*. This is a very bad economic argument, for nothing can be produced in this world *gratis*, and when we say at no price, somebody else, in this case the Indian tax-payer, makes his invisible contribution. It is therefore suggested that we should deliberate very carefully before we fix upon the types of reactor to be built at our Atomic Energy Establishment. The merits of different types should be carefully weighed by a representative expert committee.

The days of graphite-moderated natural-uranium reactors are not yet over. In fact, as Table I shows, the design of graphite-moderated reactors has improved immensely and Sir John Cockcroft informs us that the new power reactor which Britain is putting in its electrical grid in addition to coal stations will be a *graphite-moderated reactor*. The author was told by Dr. Dupuy, Chairman of the National Centre of Scientific Research in France, that France is putting up a graphite reactor for power production in the south of France, for, on account of the discovery of large quantities of U in France itself, it has been able to overcome the initial hurdle of getting quantities of uranium necessary for a graphite reactor. It appears that the American stranglehold on the Belgian uranium supply is getting loosened, and in course of the author's recent visit to Brussels, he learnt that large quantities of uranium sufficient for the construction of a graphite-moderated reactor can be had from Belgium.

§6. Research reactors for India

The Need for a Research Reactor.—It is very necessary that we make a reactor by our own efforts, out of Indian material as far as possible, but should we wait till we can achieve it? Speaking for myself, I do not foresee the time-limit when we can build up such a reactor, with our own efforts.

But should we wait so long? I think that we ought to take advantage of President Eisenhower's generous offer to help friendly nations in nuclear energy work made on December 8, 1953, which formed the subject of a debate in our Parliament on May 11, 1954, and attempts should be made to obtain a *research reactor of the University type* which is now coming into use in American universities and research institutes for fundamental research purposes. I am told that 30 American universities have applied to their A.E.C. for research reactors. Since then, the proposals have been accepted by a committee of the U.N.O. and an International Pool for Atomic Energy has been formed. The need for such a research reactor can hardly be over-emphasized. In research on nuclear science, we require a steady source of neutrons, one of the two fundamental particles out of which all nuclei are made. The primitive source was the radium-beryllium source, which gives a flux of about 10^7 neutrons per sec., if the amount of radium is a gram. This source has the disadvantage that it has inconvenient γ-rays. A polonium-beryllium source is better and is used in the Oak Ridge School of Reactor Technology but it suffers from the defect that Po has a life of 138 days only. From the great reactors of U.S.A., a flux of 10^{12} to 10^{14} neutrons per cm.^{2}/sec. is obtained, and I found in course of my recent visit that about 20 fundamental experiments on nuclear research are being carried out round the great Brookhaven graphite-moderated reactor.

The university type of research reactors are of two types—the water-boiler and the swimming-pool type. They are much smaller, but give easily a flux of 10^{12} neutrons per

cm.^{2}/sec. I enquired about the costs. I was told that we require about 10^5 dollars for the reactor, 2×10^5 dollars for the reactor building, and the fuel which is 90% enriched uranium has to be obtained from the American A.E.C. The total quantity required is 3·5 kg. costing 70,000 dollars. So the total cost comes up to $3{\cdot}70\times10^5$ dollars, nearly 2 million rupees. It is far better to get one or two reactors of this type by negotiations on government level, than wait for the day when we shall have our own graphite or heavy-water moderated reactor costing at least 3 to 4 crores of rupees.

The U.S.A. Government has recently placed 180 kg. of U^{235} at the disposal of the International Pool for Atomic Energy for distribution amongst friendly nations. We should be quick to take advantage of this offer.

I have added a list of experiments (Supplement I) which have occurred to me, and which we can carry out if we have a research reactor of this type. They are fundamental topics, but research on topics needed for the design of our own reactors may also be undertaken. We shall not then have to send 3 tons of beryllium to Saclay, as proposed by Dr. Bhabha.

Let me remind you that in spite of the huge expenditure of money on research on nuclear science and technology, we are yet far from understanding the nature of interaction between nuclear particles, in and outside the nucleus. If this were known, probably much of the cumbrous technique evolved to utilize nuclear energy would have been simplified. I may explain by a historical analogy. Mankind had observed for over two millennia the motions of the planets including the sun and the moon, under the astrological belief that if we can predict their motions in advance, we would be able to predict the destinies of nations and men. The Greek astronomers tried geometrical notions to explain these motions, and for a millennium, Greeks, Arabs and Hindus played with epicycles and deferrents and all sorts of complicated curves to understand the nature of planetary motion till the thing became so complex that a scholarly Castillian king, Alphonse XIII, who was also an astronomer, remarked that if he were present at creation, he would have given God some good advice. But when Newton discovered the law of gravitational attraction in 1680, the darkness looming over these problems for thousands of years dissolved and there was light, and since then the calculation in advance of planetary positions has become exercises in algebra. We are still in the age of epicycles and deferrents as regards nuclear science, and fundamental discoveries are still to be made. Should not the Government of free and independent India aid her scientists by helping them with money, material, men and equipment?

Supplement I

Range of research work possible with a low-power reactor

In most of these reactors the maximum thermal neutron flux inside the reactor is about 10^{12} neuts./cm.^{2}/sec. A well collimated thermal flux of about 10^6 neuts./cm.^{2}/sec. may be obtained outside the thermal column. The flux of 10^{12} neuts./cm.^{2}/sec. is sufficient for many types of scattering and diffraction studies with slow neutrons. Possible topics of study include:

A. *Physics*

1. Diffraction and scattering study with neutrons of various single energy. Single energy is produced by the use of:

(*a*) Mechanical velocity selector. Latest addition in this field is the '*fast-chopper*' designed by W. Selove at the Argonne National Laboratory.

(*b*) Time of flight velocity selector or by crystal diffraction. There are designs of different types of neutron monochromators to produce these monoenergetic neutron beams.

2. Studies in the reaction threshold : Accurate determination of reaction thresholds by monoenergetic neutron beams will furnish information on the masses of unstable isotopes.

3. Yield ratios of reactions, in which a number of products are formed. This helps in the study of competitive processes in nuclear reactions, and verification of the statistical theory of nuclear reactions.

4. Study of neutron polarization, decay of neutrons, scattering of polarized neutrons by polarized nuclei. Scattering experiments are performed to find out the law of interaction between nucleons, *viz*. between proton-proton, proton-neutron, neutron-neutron, proton or neutron and different nuclei.

All nuclei have spins, and formerly all experiments were performed using unpolarized beams. Recently these experiments have been revised using 100% polarized beams of neutrons, and nuclei which are 100% polarized. The results are found to be quite different from those obtained earlier with unpolarized beams.

5. Resonance absorption of neutrons leading to information regarding nuclear levels.

6. Energy level studies with isotopes produced in nuclear reactors by β- and γ-ray spectroscopy.

7. Study of reactor characteristics—distribution of neutrons; temperature effects on distribution of neutrons; study of reactor designs.

B. *Chemistry*

1. Relative yields of fission products produced in U, Th, etc. fissioned with neutrons of different energies. Also relative yields of fission products in photo-fission.

2. Activity method of analysis: such as in complex mixtures of rare earths, etc. Cross-sections of some of the constituents for neutron capture may differ considerably from those of others and hence estimation of their radioactive products gives their percentages.

3. Radiation chemistry, *i.e.*, effects of irradiation by pile radiation (neutron and γ-rays) on chemical valency, chemical binding, etc. Study of the primary effect of irradiation, *i.e.*, nature of the primary products; as for instance, whether H and OH are the primary products of the irradiation of H_2O or aqueous solutions.

4. Polymerization effect of radiation; study of the irradiation induced polymerization of gases and liquids, *e.g.* styrene, benzene and cyanide compounds.

5. In isotope separation problems, radiometric method is a very promising method for the analysis of the percentages of enriched isotopes. The relative radioactivity of the neutron capture product of the required isotope before and after separation will give the enrichment factor.

6. Use of radio-isotopes as tracers in various types of chemical problems, *e.g.* thermal and photochemical exchange reactions (C^{14}), chemistry of detergents (S^{35}), adsorption processes study leading to better dehumidifiers (S^{35}, P^{32}, etc.), ion exchange problems in the recovery of minerals, concentration of sugar solutions etc. (Ca^{45}, Cs^{137}), crystal formation and deposition at grain boundaries (C^{14}, Fe^{55}).

C. *Metallurgy*

1. Effect on materials for reactor construction of the intense beam of neutrons in reactor.

2. Uses of radioactive isotopes as tracers in (*a*) the study of the rôle of P and S in steel making and their removal (S^{35}, P^{32}), (*b*) the study of aging mechanism of metals, *e.g.* diffusion of C in iron (C^{14}), (*c*) absorption of Cl from salt solutions in stainless steel (Cl^{36}), (*d*) rapid determination of Ti content in iron alloys (Ti^{51}), (*e*) study of mechanism of corrosion and surface wetting of iron by organic acids (Fe^{55}, Fe^{59}).

D. *Biology, Botany and Medicine*

1. Use of radioactive isotopes as tracers in the study of—
   (*a*) Metabolism of various elements in animal and plant systems,
   (*b*) Rôle of various carbon atoms in photosynthesis, etc.

2. Therapeutic uses of the radiations from radio-isotopes, *viz.* I^{131} in toxic goitre, Au^{198} in cancer therapy, P^{32} and Au^{198} in leukaemia, etc.

3. Study of the therapeutic value of pile radiations.

4. Germicidal property of radiations, *e.g.* destruction of trichinosis cycle in pork by γ-rays.

(See N.R.C. Report: *Radioisotopes, A New Chemical Tool* by G. M. Guest of Canada.)

XIV. HEAVY MESONS

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Introduction

The name 'meson' was first used to designate the quanta of the nuclear field exactly in the same sense as the term 'photon' is used for the quanta of the electromagnetic field. Yukawa called them 'heavy quanta', as their mass, according to his theory, came out to be about 200 times the mass of an electron; but it was later agreed upon by all scientists to refer to these hypothetical quanta as 'mesons'. Terminology in science has always been a difficult job and more so at present times. Thus, when Anderson and Neddermeyer and other workers obtained conclusive evidences for the existence of particles of mass of about 200 m_e in the cosmic-rays (m_e being the mass of an electron), it was necessary to give it a name other than 'meson', and the word 'mesotron' was chosen for the cosmic-ray particle. Physicists all over the world were tempted to identify these cosmic-ray particles (mesotrons) with the heavy quanta (meson) of Yukawa because they were found to be unstable and to decay into an electron with a mean life of ~ 2 micro-seconds as required by Yukawa theory. Nevertheless both these names were freely used, 'mèsotron' for the cosmic-ray particle of mass 200 m_e and 'meson' for the quanta of the nuclear field till the classical experiments of Conversi, Pancini, and Piccioni in 1945-46 decisively proved that the 'mesotron' could never be the 'meson'. These workers discovered that when the negatively charged mesotrons of cosmic-rays stop in absorbers of low atomic number, such as carbon, they are observed to decay almost exactly like the positively charged mesotrons, although according to the theory of Fermi and Teller the negative mesotrons should have been attracted and captured by the positive charge of the carbon nucleus long before they could have had time to decay. It was found that the negative mesotrons spend a considerable time ($\sim$ one micro-second) within the carbon nucleus without having any interaction with it. But according to Yukawa's theory the heavy quanta or the mesons must have strong interaction with the nucleus. Moreover, the presence of a large percentage (75) of mesotrons in cosmic-rays at sea level also shows that these particles have very weak interaction with the àir nuclei through which they have passed. All these evidences forced scientists to give up the idea of identifying the mesotron with the meson, and the 'mesotron-meson' affair was completely at a mess at the end of 1946.

Fortunately, however, in 1947, the Bristol group of physicists led by Powell discovered in the cosmic-rays the existence of particles of mass ~ 300 m_e which curiously enough were found in many cases to decay into a particle of mass ~ 200 m_e. Powell further showed that the negatively charged particles of this mass (~ 300 m_e) are captured by nuclei and produce disintegration in spite of their life-time ($\sim 10^{-8}$ sec.) being much shorter than that of the previously discovered mesotrons. The discovered particles were found to be strongly interacting with nuclei and Powell identified them with the heavy quanta of Yukawa. As there were now two kinds of particles of mass near to each other, this called for a new nomenclature. Powell suggested the name π-meson or 'pion' for the particle of mass ~ 300 m_e and μ-meson or 'muon' for the particle of mass ~ 200 m_e. The pions are identified with the quanta of the nuclear field; they have later been produced

in the laboratory by bombarding suitable targets with highly energetic protons. An accurate measurement of their mass gave the value $273 \pm 1 \cdot 3$. Similarly the mass of the μ-meson has been found to be $207 \pm 1 \cdot 1$. The name 'mesotron' was subsequently abandoned but the word 'meson' has been retained to refer to any particle of mass intermediate between that of the proton and the electron It has also been discovered by Bjorkland *et al.* (1950) that neutral pions (called π^0-meson) are also produced along with the charged ones when energetic protons strike suitable targets. These particles decay into two photons with a very short mean life of $\sim 10^{-14}$ second and have been identified by means of the soft electron showers produced by the secondary photons.

We have presented above a short account of how the name 'meson' came into physics and of the origin of the terms, π- and μ-mesons. As the modes of production, interaction and decay of the π- and μ-mesons are now well established, we shall discuss below the growing body of experimental evidences which have proved beyond doubt the existence of other kinds of mesons in the cosmic-rays, all of which are heavier than the π- and μ-mesons and are referred to as heavy mesons.

Experimental methods

In order to understand clearly the experimental evidences we must first know the methods that are employed to collect these evidences. These are mainly the following :

1. The cloud chamber.
2. The photographic emulsion.

Both these methods make use of the ionization produced in the two media by the particles to be studied. By virtue of the varying degrees of ionization and scattering, different kinds of particles are easily recognized in photographic emulsions, whereas varying ionization and different amounts of curvature of the path of the particles in a magnetic field help them to be identified in cloud chambers. It is very difficult to operate big cloud chambers in uniform magnetic fields and in these cases a number of horizontal plates of some heavy material (usually lead) are placed in the chamber, to stop the low energy particles which are generated inside or in immediate vicinity of the chamber. In these cases exact determination of the mass is not possible although their identification with known particles can be obtained in many cases, if the particle stops inside the chamber.

The photographic emulsion technique is superior to the cloud chamber method in this respect, as 'grain density' (the number of grains per unit length) and multiple coulomb scattering along the track can be very accurately measured, and when a sufficient length of the track is available its mass can be measured with high precision. Unlike the cloud chamber the particles have to pass through the solid medium of the emulsion and hence particles of very short life-time are often found to decay in emulsions. With recent improvement in the sensitiveness of the emulsions, particles with velocity as high as $0 \cdot 8c$ can be studied with the emulsion technique. However, in emulsions the time association of two separate events recorded in the same plate is difficult in many cases, since the emulsion remains sensitive till it is developed and events occurring at wide intervals of time but near to each other in space may appear to be correlated. Moreover, one cannot use a magnetic field with photographic plates exposed at high altitudes and hence the sign of the charge of the particle cannot be determined. The first limitation is absent in all cloud chambers and both of them in chambers operated in a magnetic field.

EARLY EVIDENCES ON HEAVY MESONS

The earliest recorded photograph of a heavy meson was obtained by Leprince-Ringuet and L'heritier (1944) in a cloud chamber and the mass of the particle was determined from the dynamics of the collision of the particle with an electron and was found to be $990 \pm 120\ m_e$. Within a few months of the discovery of the π-meson and the π-μ decay, Rochester and Butler (1947) published two photographs obtained with a cloud chamber operated in a magnetic field, which showed (1) the decay of a charged particle of mass $\sim 1000\ m_e$ in the gas of the chamber into a singly charged particle and (2) the decay of a neutral particle of mass $\sim 900\ m_e$ into two charged particles. Rochester and Butler discussed various other possibilities for the interpretation of these two pictures and finally arrived at the above conclusions. The first particle referred to above was designated as a charged V-particle and the second one a neutral V-particle. Since this discovery, other workers have observed the decay events of heavy mesons both in emulsions and cloud chambers under various conditions. We shall now present chronologically the experimental evidences obtained by workers in different laboratories on the existence of various types of heavy mesons, and the nomenclatures used for them.

VARIOUS TYPES OF HEAVY MESONS

After the discovery of Rochester and Butler conclusive evidence for the existence of a neutral V-particle (formerly called the V_1^0-particle) of mass $\sim 2200\ m_e$ was obtained by Armenteros *et al.* (1951) and Leighton *et al.* (1951). The decay scheme of this particle which is at present referred to as Λ^0, is now well established from more than 200 observations and is given by

$$\Lambda^0 \rightarrow p^+ + \pi^- + 37 \text{ MeV} \quad \dots \quad (1)$$

the Q-value of 37 MeV being measured in the rest system of the Λ^0-particle. A detailed discussion of these particles, of mass greater than that of the proton and now referred to as hyperons, is outside the scope of this article. Recently, however, Cowan (1954) has obtained a photograph of a Λ^0-decay in which the negative secondary has a mass of $1850 \pm 250\ m_e$ and the positive secondary is identified as a π-meson from its decay into a μ-meson, and the Q-value for the decay process is as low as $11{\cdot}7 \pm 4$ MeV. The momenta of the particles were measured in a magnetic field and ionization by drop counting under good conditions of track formation. Cowan's picture seems to give the first clear evidence for the existence of a negative proton.

THE *TAU*-MESON

Coming back to particles of mass less than that of the protons historically the τ-mesons were discovered immediately after the charged V-particles. Brown *et al.* (1949) observed an event in photographic emulsion in which a particle of mass $\sim 1000\ m_e$ decayed at rest into three charged particles each of which was identified as a π-particle. Cloud chamber evidence of the decay of a τ-meson was obtained by Leighton and Wanlass (1952). Up to now about a dozen cases of τ-mesons have been obtained and its mass has been determined with remarkable precision from the following decay scheme:—

$$\tau^\pm \rightarrow \pi^\pm + \pi^+ + \pi^- + 75 \text{ MeV} \quad \dots \quad (2)$$

Taking the π-meson mass, $274\ m_e$, an accurate determination of the kinetic energies of the three pions gives the mass of the τ-meson as $969 \pm 5\ m_e$. Photograph of a *tau*-meson

produced in a nuclear interaction is reproduced in Plate I from Ceccarelli, Dallaporta and Merlin *et al.* (1954).

S-PARTICLES, *KAPPA*-MESONS AND *CHI*-MESONS

Bridge and Annis (1951) observed the decay of a charged particle which came to rest in one of the plates of their multi-plate cloud chamber and decayed into a lightly ionizing particle. From the small mean angle of scattering and residual ranges of the particles they concluded that the event could not be a π-μ decay but actually represented the decay of a charged heavy meson of mass $\sim$1200 m_e into a light meson (π or μ). Later a number of such stopped particles has been observed by them and these particles are now referred to as *S*-particles. An example of such an event is shown in Plate II from Bridge and Annis (1951).

Next came the observation by O'Ceallaigh (1951) in photographic emulsions of two events in which also a particle of mass $\sim$1300 m_e was brought to rest in the emulsion and decayed into a singly charged particle. In one case, of these two, the secondary particle could be definitely identified as a μ-meson which stopped in the emulsion and gave rise to a decay electron. Although, the secondary particle in the other event could be either a π- or a μ-meson, the energies of the secondaries in the two cases were widely differing. Now, if both these events represent the decay of the same particle and further if the charged decay products are the same in both cases, the inevitable conclusion is that more than one neutral particle must have been emitted in the decay process, or otherwise the secondary charged particles would have the same kinetic energy within experimental errors. O'Ceallaigh named these particles κ-mesons and gave the following decay scheme:—

$$\kappa^{\pm} \rightarrow \mu^{\pm} + ?^0 + ?^0 \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \qquad (3)$$

We shall see later that the nature of the neutral particles is still at a speculative stage.

Menon and O'Ceallaigh (1954) (reported earlier in various conferences) have later obtained evidence of a number of events in which particles of mass in the range (900-1500) m_e stopped in the emulsion and emitted π-mesons of a unique energy of about 120 MeV. This called for a different nomenclature for the primary particle, and Menon and O'Ceallaigh have used the name *chi* (χ)-meson and have given the following decay scheme:—

$$\chi^{\pm} \rightarrow \pi^{\pm} + N^0 \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \qquad (4)$$

where N^0 can be any one of the following: (1) photon, (2) neutrino, (3) π^0 and (4) a neutral *V*-particle of mass 960 m_e. The mass of the primary particle comes out to be 920 m_e if the neutral secondary is either a photon or a neutrino, 960 m_e if it is a π^0, and about 1550 m_e if it is a neutral *V*-particle of mass 960 m_e. Bridge and Annis (1951), however, obtained the first evidence of the emission of a single π-meson from a heavy particle. The primary particle (Plate III) in this case decayed in the gas of the chamber and the secondary arising out of it was scattered through a very large angle in an aluminium plate showing thereby that it has a strong nuclear interaction and hence could not be a μ-meson. The mass of the primary was within the range of the mass of the *chi*-particles found by Menon and O'Ceallaigh in emulsions.

θ^0-MESONS.

The discovery by Rochester and Butler (1947) of the decay of a neutral particle of mass $\sim$900 m_e has been followed by similar discoveries by other workers in cloud cham-

bers. A majority of the neutral V-particles is, however, represented by the decay scheme (1) and about 15% decay into two light mesons. The lighter neutral V-particles were previously called the V^0_2; but the symbol θ^0 has been proposed at Bagnéres Congress for this unstable particle, with the following decay scheme

$$(V_2^0), \theta^0 \rightarrow \pi^+ + \pi^- + 210 \text{ MeV} \quad \ldots \quad (5)$$

The Q-value of 210 MeV is measured in the rest system of the θ^0-particle, and the mass of the θ^0-particle comes out to be $(964 \pm 40)\ m_e$. We shall now present a brief analysis of the experimental evidences on the unstable particles of mass between the pion and the proton and we shall start with the discussion on θ^0-particles.

The neutral heavy meson

The evidence obtained on this particle is almost entirely confined to cloud chamber observations. Photographic emulsion evidence on neutral V-particles is very meagre.

In a θ^0-decay the plane of the two charged secondaries must also contain the point of origin of the θ^0, if the decay process involves the emission of only two secondaries. Any large deviation, from co-planarity, of the point of origin with the decay products, indicates that one or more neutral secondaries have been emitted. Fretter *et al.* (1953), Peyrou *et al.* (1952) and Armenteros *et al.* reported by Barker (1954) have examined the co-planarity of about 20 θ^0-decays and did not observe a deviation of more than 4°. It has been shown by Peyrou (1952) that if a histogram of the neutral particles is plotted with their '$\gamma\beta\delta$' values, the distribution is too sharp to be consistent with a three-body decay scheme, the third body being either a π^0 or a neutrino. γ is $1/\sqrt{1-\beta^2}$, β is v/c, δ is the angle which the θ^0 makes with the plane of the secondaries. Further if a π^0 or a γ-ray is emitted along with the two charged secondaries these would have shown electron cascades in the neighbourhood of the point of decay; but no such soft shower has been observed along with the θ^0-decay. The conclusion is that a θ^0 decay is a two-body decay process in which the two secondaries have opposite charges.

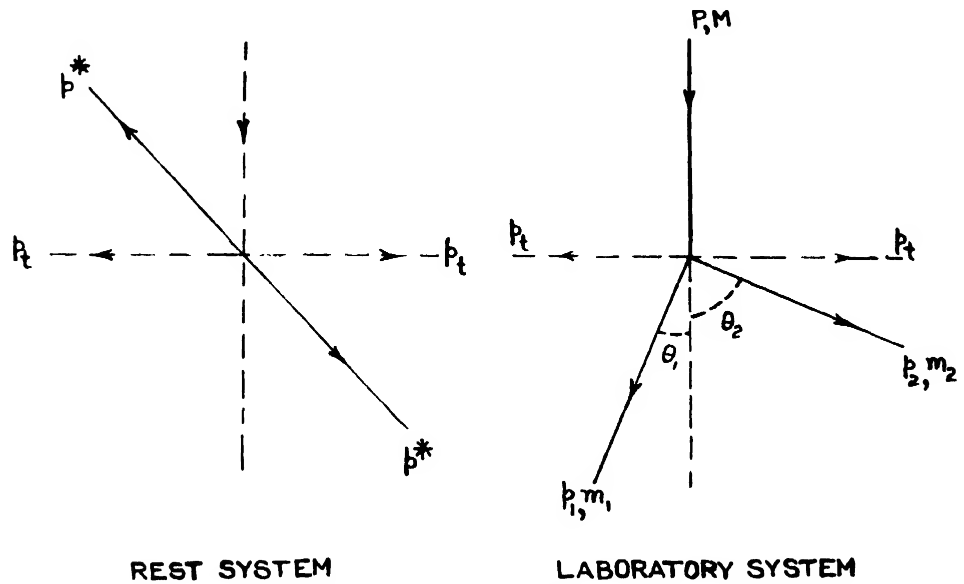

Fig. 1. Dynamics of a two-body decay process.

We shall now examine what these secondaries are and how much energy is released in the rest system of the primary. The dynamics of a two-body decay event must satisfy the following conditions in the laboratory system and in the rest system of the θ^0 (see Fig. 1).

$$\left.\begin{aligned} (M^2+P^2)^{\frac{1}{2}} &= (m_1^2+p_1^2)^{\frac{1}{2}}+(m_2^2+p_2^2)^{\frac{1}{2}} && \quad (3.1)\\ P &= p_1\cos\theta_1+p_2\cos\theta_2 && \quad (3.2)\\ p_t &= p_1\sin\theta_1 = p_2\sin\theta_2 && \quad (3.3)\\ P^2 &= p_1^2+p_2^2+2p_1p_2\cos\theta && \quad (3.4)\end{aligned}\right\}\ \textit{Laboratory system}$$

$$\left.\begin{aligned} M &= (m_1^2+p_1^2)^{\frac{1}{2}}+(m_2^2+p_2^2)^{\frac{1}{2}} && \quad (3.5)\\ p_t &= p_1\sin\theta_1 = p_2\sin\theta_2 && \quad (3.3)\end{aligned}\right\}\ \textit{Rest system of } \theta^0$$

where M and P are the mass and momentum of the primary, m_1, p_1, and m_2, p_2, mass and momenta of the secondaries which are emitted at angles θ_1 and θ_2 respectively with the parent particle. Masses are given in Rossi units. p_t is the transverse component of the momentum p^* of the secondaries in the rest system of the θ^0, and remains unchanged when transformed to the laboratory frame. Combining (3.2) and (3.3) we get

$$p_t = \frac{p_1\,p_2\,\sin\theta}{P} \quad \ldots \quad (3.6)$$

where $\theta = \theta_1+\theta_2$ is the angle between the two charged secondaries. If there are no errors in the measurement of the momenta of the secondaries p_t should always lie very close to p^*. Now under good experimental conditions p_1, p_2 and θ can be measured and equations (3.4) and (3.6) would at once provide a value for p_t. But since there is always an appreciable error in the momenta-measurements Armenteras *et al.* (1951) showed, assuming a Gaussian distribution of errors, that the probability of finding p_T in the interval dp_T is given by

$$\phi(p_T)dp_T = dp_T\int_0^{p^*}\left\{\frac{p_t}{p^*(p^{*2}-p_t^2)^{\frac{1}{2}}}\right\}\exp\left\{-\frac{(p_t-p_T)^2}{2\Delta p^2}\right\}dp_t \quad \ldots \quad (3.7)$$

where p_t refers to the theoretical distribution and p_T is the experimental value obtained in the interval dp_T. Equation (3.7) would give different theoretical distributions for $\phi(p_T)dp_T$ for different percentage errors assumed to be occurring in the momenta measurements. For an error of 15%, equation (3.7) gives the dotted curve shown in Fig. 2. The histogram shown along with this curve represents the transverse momentum data of thirteen θ^0-decays obtained by Barker (1954) with a p^* value of 200 MeV/c. It will be seen that the histogram fits very well with the theoretical dotted curve proving thereby that the θ^0-decay is a two-body process in which the momentum of the secondary particles in the rest system of the primary is about 200 MeV/c. A p^*-value of 200 MeV/c would give a Q-value of 208 MeV for decay into two π-mesons and nine of the thirteen cases give individual Q-values within 15% of 208 MeV. The Q-value is calculated for individual cases from the equation.

$$Q = M-(m_1+m_2) \quad \ldots \quad (3.8)$$

where m_1 and m_2 are taken to be the exact masses of the identified particles and M is determined from the equations of the laboratory system. Thomson *et al.* (1952) have also confirmed the view that the majority of the neutral mesons are θ^0-mesons obeying the decay scheme (5).

Although the majority of the neutral heavy mesons satisfies the decay scheme indicated by (5), one of the charged secondaries in some of the decays shows a mass

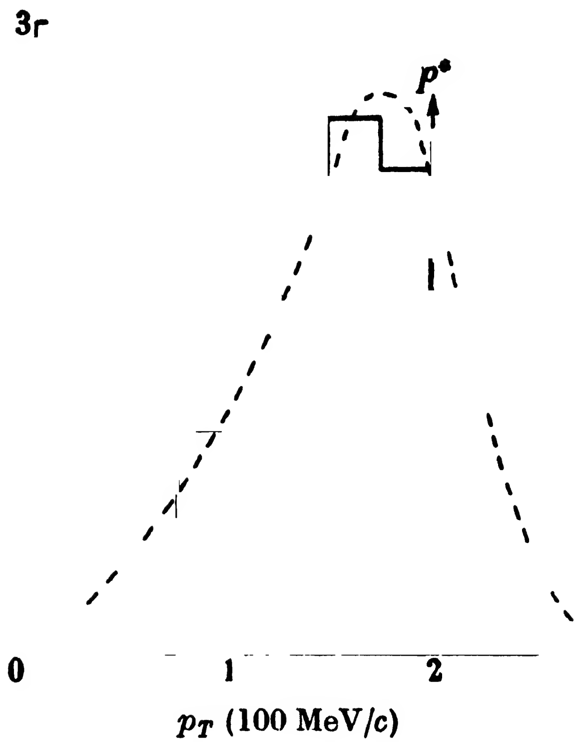

FIG. 2. Transverse momentum distribution of thirteen θ^0-particles. Dotted curve represents the theoretical distribution with an assumed error of 15% in the momenta measurements and a p^*-value of 200 MeV/c. Histogram is the experimental values for thirteen decays. From K. H. Barker (1954).

considerably higher than the pion-mass. Barker (1954) has shown that his four cases of decay which do not fall under scheme (5) and also one obtained by Leighton *et al.* (1953) can be explained by the following decay scheme:—

$$V_8{}^0 \rightarrow \tau^{\pm} + \pi^{\pm} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (5')$$

the heavier particle being taken as τ-meson only because its mass is accurately known. Latest measurements of Thomson *et al.* (1954) on 20 cases of θ^0-decay in a magnetic cloud chamber confirm the decay scheme (5) and give the value of mass of $\theta^0 = (966 \pm 10)\ m_e$ and the $Q(\pi, \pi)$ value of 214 ± 5 MeV.

Further, within statistical errors, θ^0-decay has been found to be isotropic in its rest system. There were, however, two anomalous cases which could not be explained by scheme (5). The present situation for the neutral heavy meson can be summed up by saying that the existence of the θ^0 and its mode of decay as given by (5) are certain but there might be other modes of its decay and secondary products. The existence of the $V_8{}^0$ is tentative.

THE *KAPPA*- AND *CHI*-MESONS

A. *Measurement of the masses.*

It was first shown by Bose and Chowdhury (1941) that the simultaneous measurement of mean grain spacing (grain density) and multiple coulomb scattering along the track of

a cosmic-ray particle in photographic emulsions enables one to measure the mass of the particle if the calibration curve for the mean grain spacing of a particle of known mass and energy is available. Curiously enough Bose and Chowdhury (1942) got a value of the 'mesotron' mass, as high as 300 m_e, by this method about five years earlier than the discovery of the π-meson. Bose and Chowdhuri (1942), however, interpreted the high value of the mass to be due to the presence of proton tracks in their plates along with the 'mesotron' tracks.

Later measurements of mass of charged particles from their tracks in photographic emulsions follow, in principle, the method given by Bose and Chowdhuri (1941) although the technique has now been immensely improved by (i) the use of emulsions sensitive to relativistic particles and (ii) improved theory of multiple coulomb scattering. Instead of measuring the mean grain spacing the quantity which is measured now is the grain density g^* which is defined to be the ratio of the grain density in the given track to the grain density in the track of an ultra-relativistic particle (of $\gamma\beta^2 > 10$).

Experimental evidences on *Kappa*- and *Chi*-mesons are mainly due to Menon and O'Ceallaigh (1954). As mentioned before the primary particle which gives rise on decay to a π-meson is referred to as χ (*Chi*)-meson and the one emitting a μ-meson is called a κ (*Kappa*)-meson. We reproduce in Plate IV one photograph each of a κ and a χ-meson obtained by Menon and O'Ceallaigh (1954). The mass of the primaries has been measured mostly by two different methods :—

(*a*) Scattering and residual range ($\hat{\alpha}$, R).

(*b*) Gap-length and residual range (G, R), where $\hat{\alpha}$ is the mean scattering, G the gap length and R is the residual range of the particle as determined from its track.

A third method of measuring the track-density by photo-electric device is being developed at the University of Lund. The first method is the one most extensively used

TABLE I

Data for 20 *K-particles*

From M. G. K. Menon and C. O'Ceallaigh (1954)

Event	Mass of the primary		$p\beta$ of the secondary MeV/c	Identity of the secondary	Classification of the event
	($\hat{\alpha}$, R) method	(G, R) method			
K 1	1260 ± 260	1380 ± 180	235 ± 35	μ, π or e	κ-decay
K 2	1125 ± 230	1125 ± 150	11·8	μ	κ-decay
K 3	1000 to 2000	..	144 ± 12	μ (or e)	κ-decay
K 4	1370 ± 320	..	..	..	..
K 5	1220 ± 400	950 ± 200	66 ± 11	μ (or π)	κ-decay
K 6	1035 ± 280	1050 ± 200	..	..	..
K 7	~1000	..	170 ± 29	π (or μ)	χ-decay
K 8	1460 ± 320	900 ± 200	187 ± 17	π	χ decay
K 9	~1000	..	162 ± 9	π	χ-decay
K 10	1100 ± 330	..	..	..	..
K 11	~1300	..	..	..	..
K 12	1210 ± 150	..	..	..	..
K 13	1080 ± 450	..	..	..	..
K 14	925 ± 190	..	120 ± 44	μ or e or π	κ-decay
K 15	1100 ± 170	..	184 ± 30	π (or μ or e)	χ-decay
K 16	~1100	..	153 ± 24	μ (or π)	κ-decay
K 17	1200+230	..	172 ± 17	π	χ-decay
K 18	~1500	..	315 ± 70	μ, π or e	κ-decay
K 19	1000 to 2000	..	125 ± 35	μ, π or e	κ-decay
K 20	990 ± 150	..	..	..	..

although verification by the second method is available for some cases. The results for 20 particles designated as $K\,1$, $K\,2$, $K\,3$, etc., obtained by Menon and O'Ceallaigh (1954) are given in Table I.

It will be seen from Table I that the mass values determined in the cases of $K\,5$ and $K\,8$ differ widely by the two methods and there is no verification available for the majority of the primaries by both methods.

B. *Nature of the Secondaries.*

The identification of the *secondaries* has been made by determining their mass limits by a combined measurements of the grain density g^* and multiple scattering and taking all particles of mass $> 240\ m_e$ as π-mesons and those $< 240\ m_e$ as μ-mesons. Scattering measurements alone provided values of $p\beta$ for the particles. Fig. 3 shows the distribution

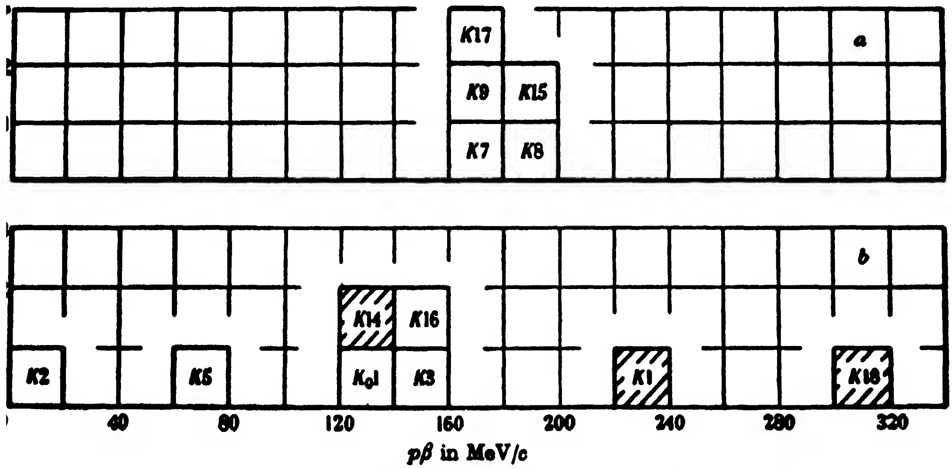

FIG. 3. Values of $p\beta$ of the secondary particles.
(*a*) π-meson secondaries arising in the decay of χ-particles. (*b*) μ-meson secondaries arising in the decay of κ-particles. In the examples shown by cross hatching, the possibility that the secondary particles were electrons could not be excluded.
From M. G. K. Menon and C. O'Ceallaigh (1954).

of $p\beta$ for thirteen secondaries. The distribution shown in Fig. 3*a* is consistent with a unique value of $p\beta$ of 180 MeV/c which is equivalent to a kinetic energy of 116 MeV and momentum 215 MeV/c for a π-meson. Menon and O'Ceallaigh (1954) therefore conclude that the decay mode is given by scheme (4):

$$\chi^{\pm} \rightarrow \pi^{\pm} + N^0$$

where N^0 may be γ or ν, π^0 or θ^0. Using the average momentum of the π-meson in χ-decay as 215 MeV/c and assuming a decay at rest in all cases, that is, an equal amount of momentum carried by the neutral particle, a value can be obtained for the mass of the χ-particle for different assumed masses of the neutral particle. The result is the following:

TABLE II

Mass of χ-meson for different assumed masses of the neutral secondary

Mass of χ	*Assumed mass of N^0*
945 m_e	γ or ν (0)
1019 m_e	π^0 (265 m_e)
1550 m_e	θ^0 (965 m_e)

It is interesting to note that the mass of χ-particle as determined for different assumed masses of N^0 satisfies the condition that it is either greater than 1500 m_e or less than 1000 m_e. The weighted mean value of the mass of χ as obtained from measurements on the primary is (1180 ± 130) m_e and hence cannot give any indication of the nature of the neutral secondary. However, the mass measurement for K 8 (Table I), an almost certain case of χ-decay by (G, R) method, gives a value 900 ± 200 m_e which is quite inconsistent with a θ° secondary. Further a search for the decay of any θ^0 secondary produced in χ-decay in the direction opposite to that of the π-meson has yielded negative results. From these arguments Menon and O'Ceallaigh conclude that the neutral secondary is either a π^0 meson or a γ-ray. Marshak (1952) has calculated the lifetime of the χ-particle with the assumption of a two-body decay process with π^0 or γ-ray as the neutral secondary and predicts a lifetime of the same order as that of the π^0-meson which is again in strong disagreement with observed lifetime ($\sim 10^{-10}$ second) of χ-particles.

The momentum spectrum of the secondary μ-mesons arising from κ-decay is shown in Fig. 3*b*. It is obvious that since the energies show a broad distribution, at least three secondaries must be emitted in the process of decay. Menon and O'Ceallaigh (1954) accordingly propose the scheme (3):

$$\kappa^{\pm} \rightarrow \mu^{\pm} + ?^0 + ?^0$$

where the two unknown neutral secondaries may be any two of γ, ν and π^0. This clearly gives six possible combinations out of which the emission of γ, ν or π^0 along with $\mu^{\pm}$ can give an integral spin for the κ-particle which is required in order that it might have a strong interaction with the nucleus. The mass of the κ-particle cannot be obtained by measuring the energy of only the charged secondary as in the case of the κ-particle. A knowledge of the maximum energy of the μ-meson emitted in the decay process can, however, give a rough estimate of its mass exactly in the same way as has been done in the case of μ-e decay. The minimum mass of the κ-particle determined in this way corresponding to the energies of K 1 and K 18 (Table I) falls within the range of direct determinations from the track of the primary particle.

C. *Production of K-particles.*

We have been differentiating between the two types, χ and κ, only because they have different modes of decay and decay products, although their masses come out to be the same within statistical errors. In what follows we shall refer to both these types as K-particles. Daniel and Perkins (1954), and Daniel, Davies, Mulvey and Perkins (1952) have been able to identify a number of K-particles in nuclear disintegrations produced by cosmic-ray protons of energy ranging from 2 GeV (GeV = 10^9 eV) to more than 50 GeV. Mass measurements were carried out by the 'grain density and scattering' method on particles with $g^* > 1{\cdot}07$, *i.e.*, $\beta < 0\ 85$. The observations of Daniel *et al.* (1952) are confined to showers of a narrow cone in which all the particles are emitted in the forward direction. These showers have been referred to as 'jets'. One example of a jet is shown in Plate V, which provides evidence for the creation of a κ-meson, a π-meson and an electron pair arising from the decay of a π^0-meson also produced in the same jet. The characteristic feature of the production of these 'jets' is that few protons are produced in them, the collision of the primary proton being confined to the 'peripheri' of the nucleus.

Daniel and Perkins (1954) have measured the masses of 325 secondary particles from disintegration produced by protons and have identified 20 K-particles. The distribution of the masses of these 20 K-particles along with 129 pions and 169 protons is shown in

Fig. 4 in the form of a histogram. Fig. 4*b* refers to artificially produced pions and protons. Although the mass measurements have not been able to differentiate *K*-particles completely from protons, the slight hump at $M = 1210$ gives strong evidence for the production of *K*-particles in nuclear disintegrations induced by protons.

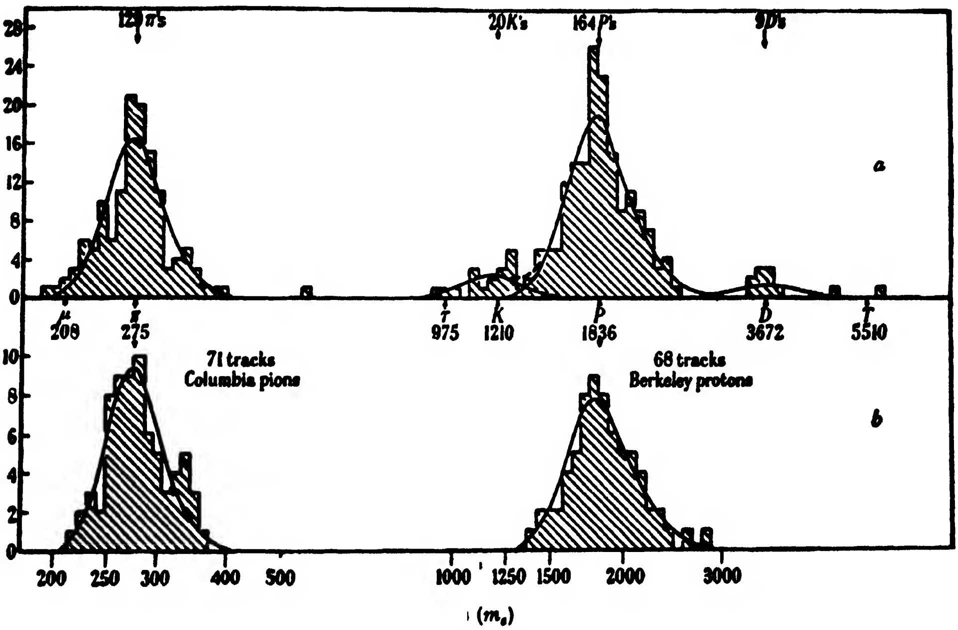

FIG. 4. Mass spectrum.
(*a*) Cosmic-ray tracks in emulsions. (*b*) Artificial pions and protons. Total 325 tracks.
From R. R. Daniel and D. H. Perkins (1954).

It has been shown by Daniel and Perkins (1954) that the ratio of the number of *K*-particles to pions increases with the multiplicity of the disintegrations from which they are produced. That is, with increasing primary energy the ratio N_K/N_π increases and its value is $0{\cdot}20 \pm 0{\cdot}06$, and $0{\cdot}5 \pm 0{\cdot}2$ for primary energies of 20 GeV and 200 GeV respectively. This is very interesting from the point of view of the Fermi statistical theory (Fermi, 1950), according to which at very high energies different nuclear quanta should be produced in numbers proportional to their statistical weights. Thus the results of Daniel and Perkins suggest that *K*-particles might also be nuclear quanta in the same sense as the pions. Since the *K*-particles are directly produced in nuclear interactions they themselves are expected to be strongly interacting. Search for such evidence by Daniel and Perkins (1954) among the 20 *K*-particles observed by them gave a negative result. About 40 *K*-particle decays have been observed up to now. Assuming all of them to be positively charged an equal number of negative heavy mesons are also expected to be observed, of which at least ten should have been captured by nuclei and should have produced nuclear disintegration. Strangely enough none has been observed so far.

Mulvey (1954) has obtained indirect evidence for a strong interaction of the *K*-particles. He analyzed a high energy 'jet' of 76 particles produced by a proton of 20,000 GeV and found that the interaction length of all the shower particles taken together was 28 ± 7 cm. in the emulsion, which is a few centimetres more than 25 cm., the interaction length in emulsions for geometric cross-section. In view of the evidence obtained by Daniel and

Perkins for the high rate of production of K-particles at very high energies. the number of K-particles produced in Mulvey's event was expected to be 50%. If all the K-particles (38 out of a total of 76) in this event were of weak interaction, the interaction length obtained by Mulvey would have been more than 50 cm. Since the interaction length obtained by Mulvey is very near to the geometric value, he concludes that the K-particles are strongly interacting. Recently, however, Rosendorff *et al.* (1954) have observed a double star connected by a heavy meson of mass $(1300 \pm 125)\ m_e$. In the same measurement they have examined a total of about 7·6 cm. length of track of six heavy mesons which combined with 10 cm. length observed by the Bristol group gives one nuclear interaction in 17·6 cm. indicating a geometric mean free path for the heavy meson.

Another point of theoretical interest is the production of K-particles in pairs. If they are created in pairs, they will be Fermions with half integral spin and if produced singly they will be Bosons with an integral spin. No pair formation of K-particles has yet been observed although the experimental evidence so far is not decisive. However, the evidences obtained indicate that the K-particles are actually Bosons. Recently one example of the decay of a K-meson (identified as a χ-meson) has been observed in Ilford G 5 stripped emulsions exposed to radiations from a copper target bombarded by 3 GeV protons from the Brookhaven cosmotron by Hill, Salant *et al.* (1954). The secondary has been identified as a π-meson of $p\beta(163 \pm 10)$ MeV/c leading to a Q-value of (211 ± 20) MeV if the neutral secondary is assumed to be a π^0 $(263{\cdot}7\ m_e)$. If this evidence is accepted as an example of artificial creation of χ-meson by protons then there is no doubt that the χ-mesons are of integral spin.

THE *TAU*-MESON

The name τ-meson was given by Brown *et al.* (1949) to a singly charged particle which decayed into three charged secondaries of almost equal mass. Rochester and Butler (1953) have collected all the data for τ-meson secondaries and shown that in all the cases (i) the secondaries are coplanar within experimental errors and (ii) the three secondaries conserve momentum. Hence it is natural to conclude that the three charged secondaries are the only decay products of the τ-meson and accordingly the decay scheme is given by (2):

$$\tau^{\pm} \rightarrow \pi^{+} + \pi^{-} + \pi^{\pm} + Q(75 \text{ MeV})$$

That the secondaries are π-mesons has been proved by either a π-μ decay or the production of a star at the end of its range. Recently Ceccarelli *et al.* (1954) have obtained the photograph of a τ-meson created in a nuclear interaction, shown in Plate I. The mass of the primary particle (τ-meson) was first determined directly from scattering and grain density measurements in two adjacent plates in one of which the particle was produced and then decayed in the other. The mass-value obtained was $955 \pm 100\ m_e$. The three secondary particles marked A, B and C were identified as π-mesons and their kinetic energies determined. This enabled Ceccarelli *et al.* to calculate the Q-value of decay and the mass of the τ-meson very accurately. These are $Q = 78{\cdot}2 \pm 4{\cdot}8$ MeV and $m_\tau = 975 \pm 12\ m_e$. Lock and Major (1954) have recently obtained a τ-meson decay and the m_τ and Q-values from this event are $(983 \pm 10)\ m_e$ and $(79 \pm 3{\cdot}5)$ MeV respectively. We reproduce the data for all the τ-mesons obtained so far from Lock and Major's compilation.

There is some evidence obtained by Hodgson (1954) and Herz *et al.* (1953) that τ-mesons are emitted more frequently from the hydrogen nucleus than from heavier nuclei. The number of τ's and π's obtained in plates exposed at high altitude under ice

TABLE III

The Q-Values of τ-meson decay, observed in photographic emulsions

From Lock and Major (1954)

Authors	Q (MeV)	m_τ (m_e)
1. Brown *et al.* (1940)	65 ± 8	955 ± 17
2. Harding (1950); Herz *et al.* (1953)	76 ± 15	977 ± 33
3. Harding (1950); Herz *et al.* (1953)	69 ± 8	963 ± 17
4. Fowler *et al.* (1951)	75 ± 4	975 ± 10
5. Hodgson (1951); Herz *et al.* (1953)	$73{\cdot}5\pm7$	972 ± 15
6. Ceccarelli *et al.* (1952)	$86{\cdot}5\pm7{\cdot}5$	988 ± 16
7. Menon (1952)	75	975
8. Ceccarelli *et al.* (1953)	78 ± 5	981 ± 11
9. Baroni *et al.* (1954)	75 ± 4	975 ± 10
10. Lock *et al.* (1954)	$79\pm3{\cdot}5$	983 ± 10
11. Panetti *et al.* (1953)	$74{\cdot}7\pm3{\cdot}5$	974 ± 10

Average $Q = (75{\cdot}2\pm3)$MeV
" $m_\tau = (975\pm9)m_e$
" $m_\pi = (276\pm2)m_e$

has been 3 and 686 respectively whereas the same number obtained by the Bristol group under heavy materials is 2 and 6460. This gives

$$N_\tau/N_\pi = 0{\cdot}004^{+0{\cdot}004}_{-0{\cdot}002}\text{ under ice and } = 0{\cdot}0003^{+0{\cdot}0004}_{-0{\cdot}0002}$$

for plates exposed under heavy materials. Though not conclusive, there is strong evidence for a preferential creation of τ-mesons in hydrogen nuclei.

S-PARTICLES AND CHARGED *V*-PARTICLES

The S-particles and charged V-particles have been discovered during the study of penetrating showers in cloud chambers. Example of an S-particle is shown in Plate II and that of a charged V-particle in Plate III both obtained by Bridge and Annis (1951). The mass measurements in cloud chambers are in few cases as accurate as that obtained in photographic emulsions. Moreover the secondaries do not stop inside the chamber in most cases; but the mean scattering in a number of metal plates combined with an estimate of the ionization enables one to identify the secondary with any one of the known charged particles. Only when the secondary is brought to rest in one of the metal plates can its momentum be measured accurately. The low scattering and high momentum of the secondaries distinguish S- and V-decay from a π-μ decay. Bridge *et al.* (1953) have analysed eight S-particles and have shown that if the secondaries are assumed to be π-mesons their momenta are consistent with a unique value of 215 MeV/c whereas if the secondaries are assumed to be μ-mesons the secondary momenta show a broad distribution. We have mentioned earlier that the χ-mesons detected in photographic emulsions decay into a π-meson of unique momentum of about 210 MeV/c and the κ-mesons decay into μ-mesons of various momenta up to 300 MeV/c. The S- and V-particles can therefore be identified with any one of the K-mesons or they might be a mixture of both. The average value of the masses of the S- and V-particles as obtained by Bridge *et al.* is 1200^{+270}_{-200} which points also towards the same conclusion. The most extensive measurements on charged V-particles are those obtained by Astbury *et al.* (1953)

working at high altitudes on the Pic-du-Midi (2,867 m.) and on the Jungfraujoch (3,460 m.) with a circular cloud chamber operated in a magnetic field. In only three of the twenty-five cases presented below the momenta of the primaries could be measured as shown in Table IV.

TABLE IV

Data for twenty-five charged V-*particles*

From C. C. Butler (1954)

No.	Sign	Primary momentum MeV/c	Primary ionization (min.)	Secondary momentum MeV/c	Angle of decay	Transverse momentum p_T MeV/c
P 2	−		4 to 8	178 ± 70	$24{\cdot}5 \pm 2$	74 ± 29
P 3	−			194 ± 8	100 ± 5	191 ± 10
P 6	−			760 ± 170	$12{\cdot}5 \pm 1$	164 ± 40
P 7	+			792 ± 67	$11{\cdot}5 \pm 2$	158 ± 30
P 9	−			503 ± 33	$15{\cdot}5 \pm 2$	134 ± 19
P 12	−	1400 ± 240		448 ± 61	27 ± 1	202 ± 28
P 17	−			608 ± 90	23 ± 3	238 ± 43
P 19	−			347 ± 39	$21{\cdot}5 \pm 1$	126 ± 15
P 20	+			546 ± 85	28 ± 4	256 ± 51
P 27	+			822 ± 107	$15{\cdot}5 \pm 2$	220 ± 40
P 29	−			174 ± 9	82 ± 5	172 ± 9
P 30	−			222 ± 22	35 ± 2	172 ± 14
P 31	−			92 ± 15	71 ± 5	87 ± 14
P 32	−			161 ± 26	59 ± 5	138 ± 23
P 33	+	368 ± 52	2 to 3	107 ± 25	70 ± 4	101 ± 19
P 34	−			150 ± 9	74 ± 5	144 ± 10
P 35	−			245 ± 10	46 ± 2	176 ± 9
P 36	−			541 ± 97	$26{\cdot}5 \pm 3$	241 ± 48
P 37	+			436 ± 61	30 ± 2	218 ± 33
J 4	+ ?			41 ± 4	89 ± 3	41 ± 4
J 6	−	350 ± 50	2 to 4	280 ± 60	53 ± 2	220 ± 40
J 11	+			490 ± 80	28 ± 2	230 ± 40
J 12	+			510 ± 40	18 ± 2	160 ± 10
J 13	+			124 ± 6	$15{\cdot}5 \pm 3$	33 ± 2
J 14	−			260 ± 60	19 ± 3	84 ± 20

P = decays observed by the Pic-du-Midi group.
J = decays observed by the Jungfraujoch group.

In Fig. 5 is shown the p_T-distribution of these twenty-five particles in the form of a histogram. The dotted curve A represents the theoretical distribution with p^* value of 215 MeV/c and the dotted curve B has been drawn for a three-body decay scheme of a K-particle of mass $1150\, m_e$. Although the two theoretical curves overlap to a large extent, the histogram for the twenty-five particles fits the curve B more closely than the curve A, from which it is concluded that a majority of the $V^{\pm}$-particles are κ-particles.

The nature of the neutral secondary or secondaries in $V^{\pm}$-decays is still unknown. As in the case of K-mesons the neutral counterpart in $V^{\pm}$- and S-decays may be one (or more) of any of the known neutral particles ν, γ, π^0 or θ^0. Bridge *et al.* (1953) have obtained four cases of soft electron cascades associated with S-decay in the proper direction indicating the presence of either π^0 or γ with the decay, the experimental evidence being more consistent with the γ-ray secondary. An unusual photograph (case P2 of Table IV), obtained by Armenteros *et al.* (1952) (Plate VI) shows apparently the decay of the neutral particle emitted in the process of a V-decay. A negative particle (Track 1) decays just below the lead plate, the angle of decay being $24{\cdot}5^0$; there is another fork a

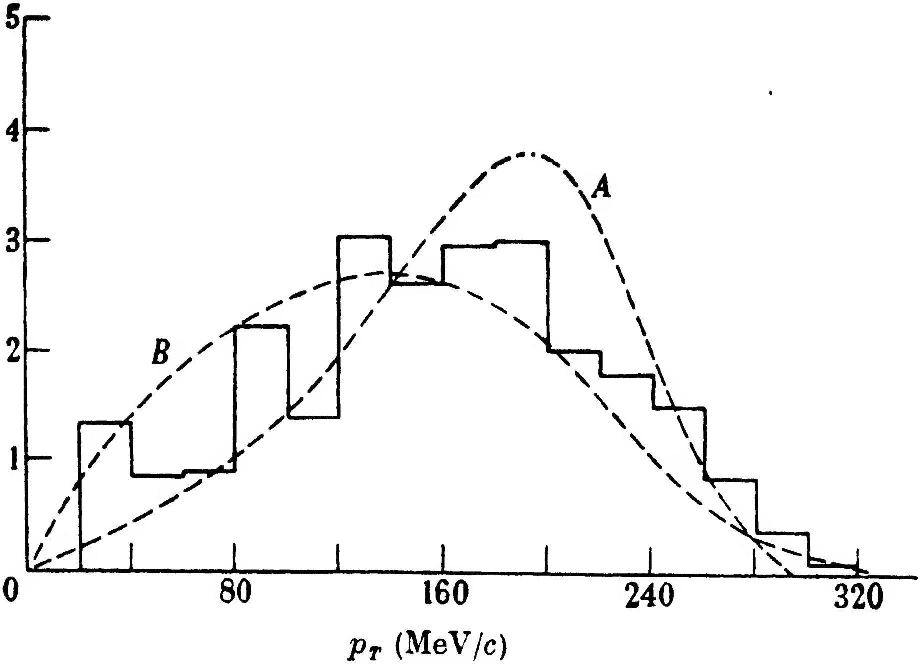

FIG. 5. p_T-distribution for 25 charged V-particles.
Curve A—Theoretical distribution for $p^* = 215$ MeV/c normalized to 25 events. Curve B—Distribution for a three body decay scheme for a κ-particle of mass 1150 m_e normalized to 25 events.
From C. C. Butler (1954).

little below (Tracks 3 and 4) which most probably represents a θ^0-decay. The plane of 3 and 4 passes through the point of decay of 1. If this photograph actually represents a double decay then the mass of the χ-meson will be 1660 m_e assuming a mass of 960 m_e for θ^0-mass.

Another interesting decay event has been obtained by Sinha and Das (1954) (Plate VII). A heavily ionizing particle created in a nuclear interaction from the sixth lead plate stops in the next plate and emits a particle which when viewed stereoscopically is seen to proceed almost at right angles to the primary. The secondary particle increases in ionization after crossing the tenth plate and from its low scattering is identified to be an L-meson (π or μ) of momentum 158 ± 18 MeV/c. Assuming the S-event as a two-body decay process Sinha and Das searched for any evidence of the neutral secondary in a direction opposite to that of the charged secondary. It was found that the track CDD' which increases in ionization while going upwards, if produced back meets the track AS produced inside the chamber but well outside the illuminated volume of the chamber. The track CDD' stops inside the chamber and its range and large scattering identify this particle as a π-meson of momentum 135 ± 10 MeV/c. If it is supposed that the neutral particle emitted at S has decayed into two π-mesons (one of which is CDD') at the point where CDD' and AS meet, it is found from the angle between CDD' and AS that the forward momenta of the two pions would add up to give a momentum of 151 MeV/c to the neutral secondary which is remarkably close to the momentum (158 ± 18) MeV/c of the charged secondary. It is concluded that this photograph probably represents a double decay of the type (6).

$$K^{\pm} \rightarrow L^{\pm} + \theta^0 (\rightarrow \pi^+ + \pi^-) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (6)$$

The mass of the primary particle (OS) comes out to be $(1450 \pm 100)m_e$ according to scheme (6) taking the mass of θ^0 as $960\,m_e$. Although the other leg of the θ^0-decay is not visible it is unlikely that the track CDD', which undoubtedly goes upwards and intersects the line SA is just another stray track unconnected with the decay event at S.

Thus all the data so far obtained for the S- and V-particles point out that they are actually a mixture of both κ- and χ-mesons obtained in photographic emulsions. We shall now present an important result obtained recently by Kim, Burwell *et al.* (1954) on the charge asymmetry of $V^{\pm}$-decay events in a magnetic cloud chamber. Altogether thirteen V^+-decays and eighteen V^--decays have been observed and the transverse components of the momenta of the secondaries fit in very closely with the theoretical momenta distribution for a *two-body* decay process of (p_t = 220 MeV/c) for the *positive* primaries and a *three-body* decay process (maximum p_t = 220 MeV/c) for the negative primaries. This result would at once identify V^+-mesons with χ-particles and V^--mesons with the κ-particles of photographic emulsions. Kim *et al.* (1954) have also observed that the V^--mesons apparently decay with a mean life shorter than that of the V^+-mesons.

Lastly we want to mention the possible existence of a particle of mass $\sim 500\,m_e$, called the ζ-meson, evidence for which has been obtained in photographic emulsions by Perkins (1952) and Shapiro (1952). The mass obtained by these authors is $m_\zeta = 520 \pm 90\,m_e$ with the following decay scheme

$$\zeta^{\pm} \rightarrow \pi^{\pm} + \pi^0 \quad \ldots \quad (7)$$

with a Q-value which is less than 6 MeV. The angular deflexion produced at the point of decay of the ζ-meson has been very small ($<2°$) and this makes the evidence for its existence unreliable.

Mean life of the heavy mesons.

The data so far collected for the mass, nature of secondaries and mode of decay of the different types of heavy mesons are to some extent satisfactory; but those regarding their mean lives are very poor. This is due to the fact that the heavy mesons are generally produced in the material placed above the cloud chamber and hence those having a very short lifetime, decay before they enter the cloud chamber and those with an appreciably longer lifetime pass out of the chamber undecayed. It is, first of all, assumed that all charged heavy mesons have the same mean life and then all the available track lengths of the primaries are collected and transformed into corresponding time t of flights in the rest system by the equation,

$$t = \frac{l}{\gamma\beta c} \quad \ldots \quad (8)$$

where l is the measured length and $\gamma\beta\,(= P/Mc)$ is directly obtained from the estimated ionization of the primary if it is more than minimum. If the particle decays with high momentum and is of minimum ionization, only direct measurement of its momentum in a magnetic field and an assumed mass for the primary can give the proper time of flight before decay. Wilson and Butler (1952) have explained how these observational data can be corrected and converted into the mean life of the $V^{\pm}$-mesons. A detailed analysis of the $V^{\pm}$-mesons made by the Manchester group and reported by Newth (1954) gives the mean life between 4×10^{-9} and 10^{-8} second.

Bridge, Peyrou, Rossi and Safford (1953) using a multiplate chamber have analyzed the decay event of seven S-particles and find that the mean life lies within the range 10^{-9} to 2×10^{-8} sec. The single event of Sinha and Das (Plate VIII, 1954), however, gives a

lifetime between 6×10^{-10} and 4×10^{-10} sec., since the particle has decayed within 7 cm. of its origin and its β-value lies between 0·3 and 0·5 corresponding to its ionization limits of 3 to 6 times minimum. This indicates that its lifetime is at least of an order of magnitude less than that given by Bridge *et al.* or the Manchester group, and hence leads to the conclusion that the particle belongs to a different group. The higher mass of the primary ($\sim$1450 m_e) might be the cause of this shorter lifetime.

The mean life of the θ^0 has been determined by Astbury *et al.* for twelve particles by a method given by Bartlett (1953) and they find the value

$$\tau = 1{\cdot}6^{+1{\cdot}6}_{-0{\cdot}6} \times 10^{-10} \text{ second.}$$

Fretter *et al.* (1953) examined eleven sure cases of θ^0-decay and arrived at a mean life of $4 \pm 3 \times 10^{-10}$ second. The statistics of all mean life measurements for the heavy mesons are very poor, but it appears that the mean life of the neutral primaries is less than one-tenth of that of the charged heavy mesons. But there are individual exceptions.

Future outlook

Goldhaber (1953) has made an attempt to explain the production, absorption and decay of all the heavy mesons by assuming that besides the π-mesons only the θ^0 is fundamental and all the other heavy unstable particles are 'compounds' with either a nucleon or a pion. In this scheme the Λ^0 will be a 'compound' (θ^0+neutron) and the $\tau^\pm$-meson a compound ($\theta^0+\pi^\pm$) where the measured masses of the Λ^0 and $\tau^\pm$ give the binding energies of Λ^0 and $\tau^\pm$ to be 310 and 130 MeV respectively. Results reported in the foregoing pages suggest that the different particles observed as χ, κ, $V^\pm$ and $\tau^\pm$ may not be actually different *particles* but only represent different *modes of decay* of the same particle $\tau^\pm$. According to this,

$$\tau^\pm \rightarrow \mu^\pm + ?^0 + ?^0 \quad .. \quad \kappa\text{-mode,}$$

$$\tau^\pm \rightarrow \pi^\pm + \gamma \text{ or } \pi^0 \quad .. \quad \chi\text{-mode,}$$

are two different modes of decay of the $\tau^\pm$-meson in addition to the well-established mode of decay into three pions. Goldhaber then shows that this scheme predicts the production of Λ^0, θ^0 in pairs. Recently Fowler *et al.* (1954) have obtained evidence for this pair production in a high pressure diffusion cloud chamber filled with hydrogen and exposed to the π^--beam from the Brookhaven cosmotron. The cloud chamber was operated in a magnetic field of 10,500 gauss. Plate VIII shows the picture of a pair of neutral heavy mesons. The pair '*a*' (1*a*, 2*a*) is probably due to the decay of Λ^0 into a proton and negative π-meson and the pair '*b*' (1*b*, 2*b*) represents the decay of a θ^0 into a pair of π-mesons. Fowler *et al.* have also obtained two other cases of pair production of heavy mesons.

The idea of considering the unstable heavy particles as 'compounds' of 'elementary' particles has been supported by Cocconi (1954) who predicts that one would observe a difference in the number of heavy mesons produced relative to π-mesons at high energies if these particles are compounds instead of being 'elementary' as proposed by Fermi (1950). According to Fermi the probability of their production increases with energy and become asymptotically constant at high energies. But if they are compounds of θ^0 with pions the probability of their production will increase up to energies of several GeV, which would then decrease to a very small value for energies $\sim 10^{12}$ eV.

Thus we find that in order to understand their nature more fully future experiments on these heavy unstable particles should not only provide us with a better statistics for their mass, mean life, decay products and Q-values, but should also aim at determining the rate of production of these particles at very great energies and also their simultaneous production in pairs.

It is a pleasure to acknowledge with thanks the help extended to me by Miss Nilima Basu, M.Sc., during the preparation of this article. I also wish to acknowledge my indebtedness to the various workers on 'heavy mesons', whose data and photographs I have used in this article.

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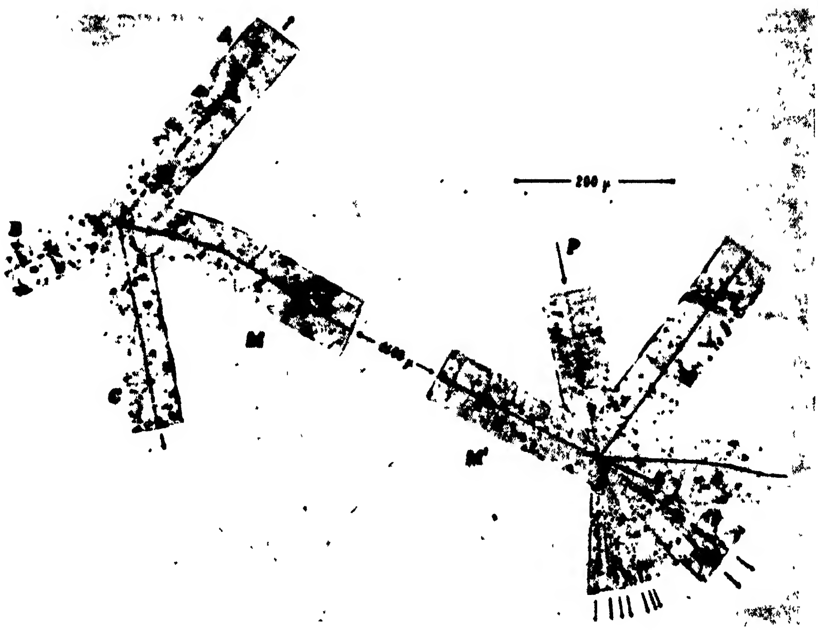
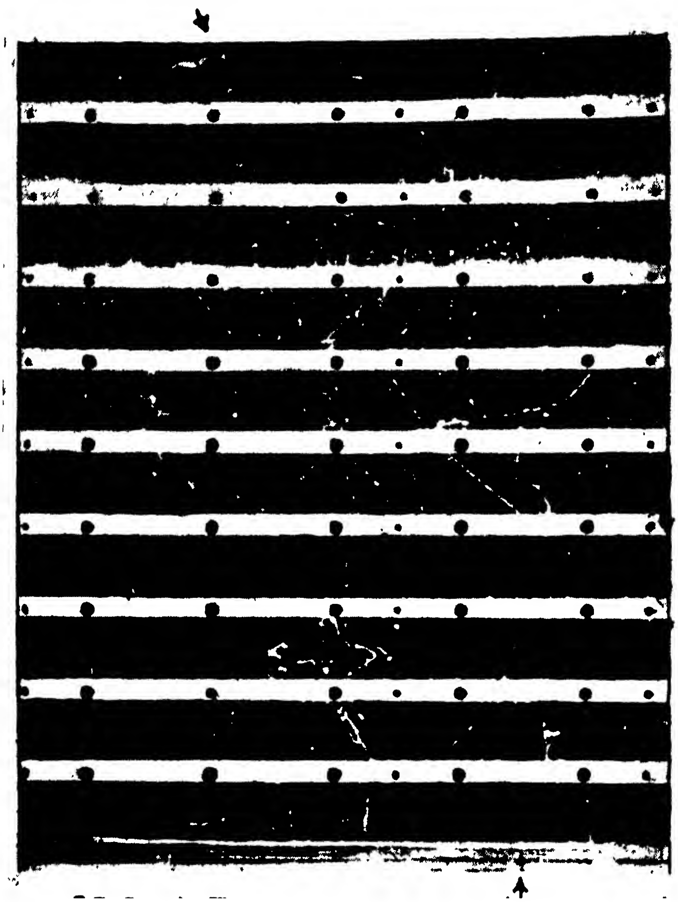


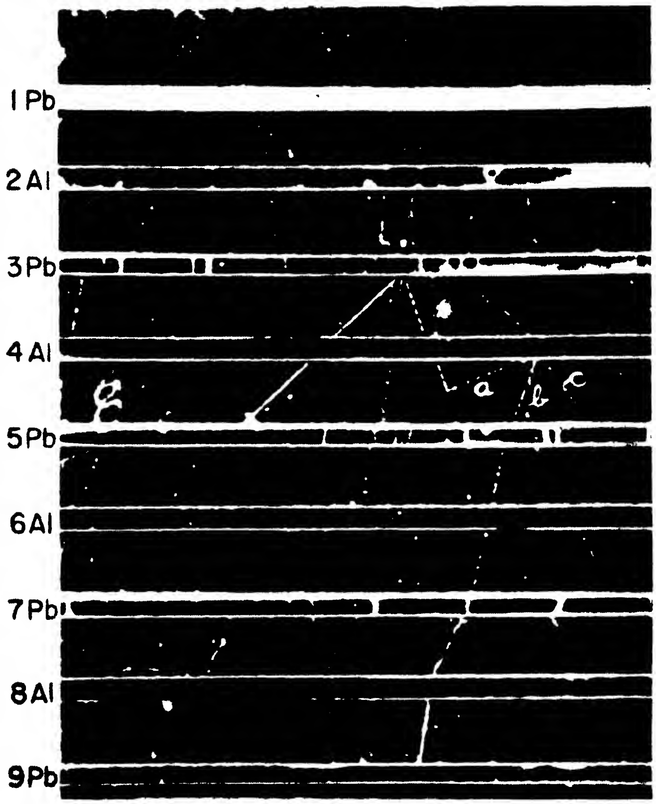
Production and decay of a τ-meson, $M'M$ is track of the τ-meson and A, B, C are the tracks of the three pions.

From Ceccarelli *et al.* (1954).



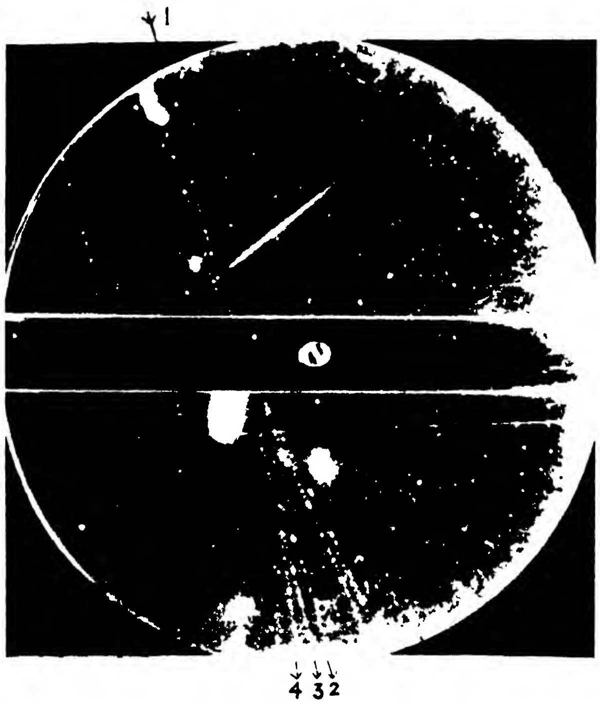
Decay of an S-particle. The primary particle (indicated by an arrow) enters the chamber from above, stops in sixth plate and decays into a minimum ionizing particle.

From Bridge and Annis (1951).



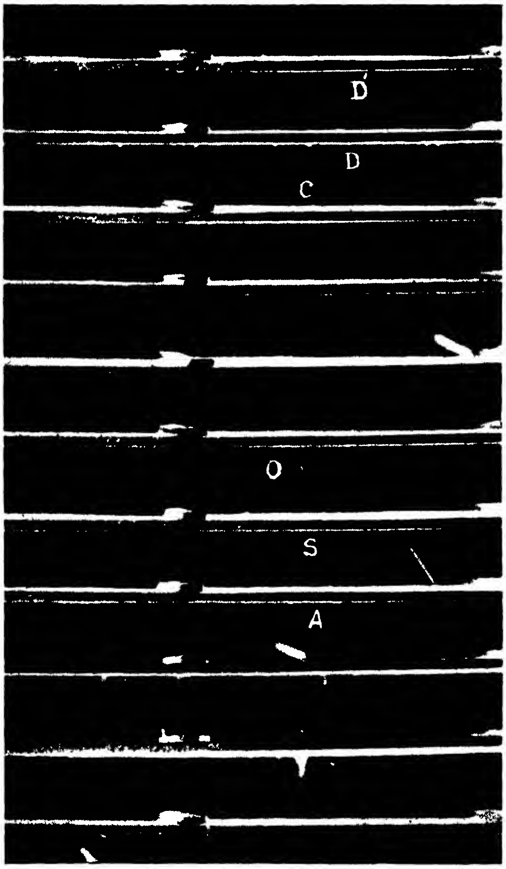
Decay of a charged *V*-particle. The primary charged *V*-particle is produced in an interaction in the third plate (0·26 in. of lead), passes through a 0·31 in. aluminium plate and then decays in the gas of the chamber to form particle (*a*). This particle is scattered through a large angle in the aluminium plate and emerges as particle (*b*) which slows down and finally stops in the ninth plate. This large angle scattering identifies the secondary as a π-meson.

From Bridge and Annis (1951).



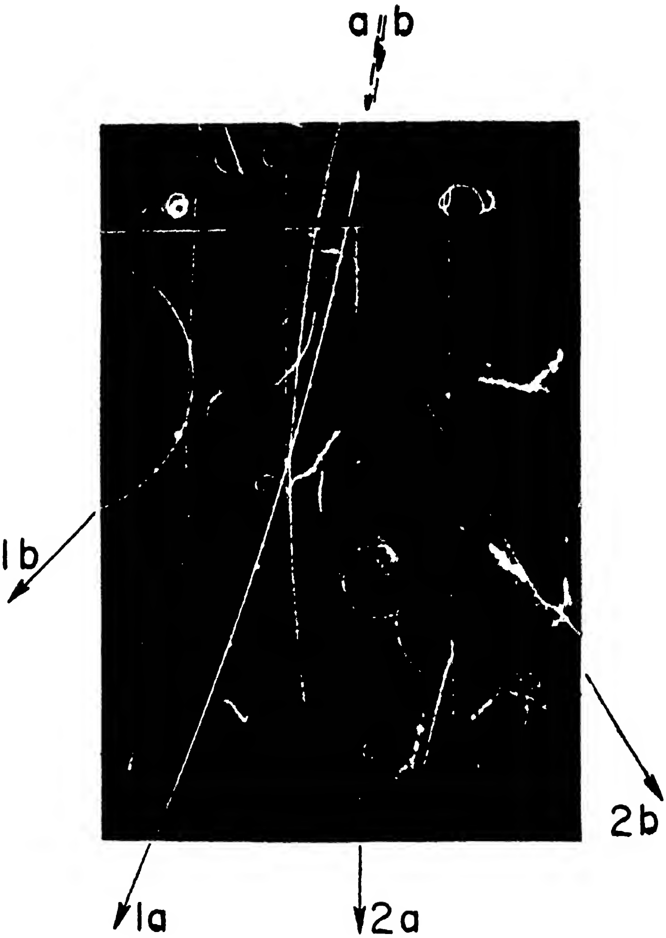
Photograph of a double decay. The particle, indicated by track 1, decays a few centimetres below the central lead plate into a single charged particle (track 2). This point of decay and the pair of tracks (3 and 4) lie in one plane. The interpretation of this photograph (event P 2 of Table IV) is that the tracks 3 and 4 are the decay products of the neutral secondary emitted from the point of decay of primary charged particle (track 1).

From Astbury *et al.* (1952).



Photograph of an S-event. The S-particle is produced at O in the sixth lead plate, and decays at S in the next plate giving rise to the secondary SA, recognized as an L-meson. The track AS produced upwards meets the track $D'DC$ produced, in space. The component of the momentum of CDD', in the direction AS is almost exactly half the momentum of the particle SA at S. It is concluded that the track CDD', which undoubtedly goes upwards, is one leg of the decay of a θ^0 produced at S.

(Sinha and Das, private communication.)



Photograph of simultaneous production of Λ^0 and a θ^0. The pair a ($1a$, $2a$) represents the decay of a Λ^0 and the pair b ($1b$, $2b$) represents the decay of a θ^0. This photograph was obtained in a diffusion cloud chamber filled with hydrogen at a pressure of 15 atmospheres and exposed to π-beam from the Brookhaven cosmotron.

From Fowler *et al.* (1954).

XV. FISH AND FISHERIES IN ANCIENT INDIA[1]

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(*Received for publication on January 18, 1955*)

INTRODUCTION

The keen interest Dr. D. M. Bose has always shown in matters relating to science and culture has prompted me to contribute this article for his Seventieth Birthday Commemoration Volume as a humble tribute to his great scholarship and long record of service to the intellectual pursuits of mankind. The scientific achievements of India in the realm of biological sciences are little known among the historians of science and as the writer has used since 1935 his leisure hours in a scientific understanding of the knowledge of fish and fisheries of the ancient Hindus, it seems opportune to summarize here the information that has so far been collected on the subject.

It may be recalled that Chaudhuri (1918: cxxxix), while dealing with the history of Indian ichthyology, remarked that

> 'I do not want to tell you anything today about the number of species of fish enumerated or referred in the Indian Medical work *Susrut* or other ancient Sanskrit or Pali texts, nor will I mention those names which are inscribed in the edicts of the good King Asoka, because the importance of these enumerations is purely historical and the records do not actually lead us towards the advancement of our knowledge of Indian ichthyology.'

Recent studies, as detailed below, have, however, shown that a proper analysis and thorough understanding of the material contained on fish and fisheries in the ancient Sanskrit and Pali texts not only materially advances our knowledge of Indian ichthyology but is essential to appraise the modern practices and prejudices for a rational programme of fishery development in the country. It must be clearly understood that the society in India still centres round the rural and civic communities in which tradition plays a very important rôle in everyday life. It is unfortunately little realized that ancient Indian literature and traditions can be coaxed, through patient and laborious studies, to yield gems of knowledge unrivalled in modern science. Above all, it is essential that the science students of any country must know the social and cultural background of science of that country. In fact, the time has now come when in our research pursuits serious attempts should be made to reconstruct our approach to fisheries against the background of ancient knowledge as interpreted in the light of modern scientific understanding. It is only then that we can get public support for the implementation of our much needed development schemes.

SUŚRUTA'S CONTRIBUTION TO ICHTHYOLOGY.

Since Chaudhuri made a specific reference to Suśruta's medical work and to Aśoka's pillar edicts, I shall briefly refer to their respective contributions to Indian ichthyology disregarding, for the time being, chronological sequence that should be followed in a paper of this nature.

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[1] Adopted from a popular lecture delivered on November 5, 1954, at the Indian Museum, Calcutta.

Fish as Food.—Suśruta not only enumerated a number of species of fish of food value but also gave their relative medicinal properties. I have not yet fully analyzed and understood this remarkable medical work but the point that immediately arrested my attention was the statement made therein that freshwater fish are more nutritious than the marine fish. Enquiries made among medical scholars and biochemists have shown that scientific information on this point is practically nil but some light has been thrown by two communications that I have received. In a recent article, George and Shah (1954: 69) have shown that the nutritive value in calories per 100 gm. of muscle of the marine lobster *Panulirus polyphagus* (Herbst) is 101·390 while that of the freshwater prawn *Palaemon carcinus* (Henderson and Mathai) is 119·103, thereby supporting the contention of Suśruta, Charaka and the *Bhāvaprakāśa*. I do not for a moment wish to say that traditions should be accepted at their face value, nevertheless it seems that there is certain element of truth in Suśruta's statement which could not be discarded straight away.

I have been informed by Dr. D. B. Finn, Director, Fisheries Division, Food and Agriculture Organization of the United Nations, that in marine fish there are nonprotein nitrogenous components such as trimethylamine oxide and urea which make the marine fish putrefy more readily and thereby reduce their palatability and sale value. On the other hand, freshwater fish do not contain these components and can stay fresh for a relatively much longer period. In ancient times when refrigeration was not known, the relatively high merit of freshwater fish as an article of diet in a tropical country like India could thus be readily understood.

It will be seen that Suśruta poses many important problems for medical people, nutrition experts and biochemists that need experimental study in our laboratories so that the knowledge embodied in his *saṃhitā* can be used for the good of mankind.

Form and Locomotion of Fishes.—This subject has been dealt with already in some detail in my two papers (1935; 1952: 162) but Suśruta's conception of correlation between form and locomotion of fishes is of such fundamental importance in ichthyology that I wish to reiterate it here so as to show how unjustified were Chaudhuri's remarks. A free translation of Suśruta's passage reads as:

> 'The river fish are bulky in the middle because they move with their head and tail; the lake and tank fish are similar to the above but are characterized by a relatively smaller head; the spring and pool fish, as they have not much space to move about, are extremely deep behind the head; the fishes of the torrents are traditionally well known by the possession of two characteristics, the greatly flattened body on account of their habit of crawling with the chest, and a relatively reduced anterior part of the body.'

In his three couplets, Suśruta has brought out very accurately the ecological classification of freshwater fishes, correlation between form and locomotion of fishes and above all a philosophical interpretation of the phenomena observed by him against the background of 'adaptations'. Chronologically, this is perhaps the earliest (A.D. 200 to A.D. 500) biological statement which can withstand any test of analysis in the light of modern scientific knowledge.

Aśoka's Contribution to Ichthyology

Prohibited Fishes.—In his pillar edict V, Aśoka enumerated five aquatic animals and declared them inviolable under the law because they 'do not come into man's use, nor are eaten by men.' These animals are : (i) boneless fishes (sharks), (ii) eels, (iii) freshwater

porpoises, (iv) skates and rays, and (v) globe or porcupine fishes. I (1950: 49) have already explained the significance of this protection and shown that according to the law-books of the Hindus misshapen fishes, such as eel, globe-fish and skate, are not to be eaten. Fishes that feed on flesh, such as sharks, are also prohibited. The five protected aquatic animals are still not eaten by the orthodox Hindus. Globe-fishes are, in fact, poisonous and even on that account should be prohibited as food.

Fishery Legislation.—After declaring the above five aquatic animals as inviolable, Aśoka thus legislates for the conservation of the fishery as a whole:

> 'Fish are inviolable and must not be sold on the three *Chaturmāsīs*, (and) on the Tishyā full moon, during three days, *viz.* the fourteenth, fifteenth and the first *tithi* and invariably on every fast day.'
>
> 'And during these same days no other classes of animals which are in the elephant park and the preserves of the fishermen must be killed.'

I have fully discussed elsewhere (1950: 53) the significance of this law and have advanced the following scientific analysis of its various points:

1. No fish should be caught on the 14th and 15th day of the moon and the first day after the full moon during the period of the 3rd *Chaturmāsī* (*Śrāvaṇa*, July-August; *Bhādra*, August-September; *Āśvina*, September-October and *Kārtika*, October-November) = 12 days.
2. No fish should be caught on the 14th and 15th day of the moon and the 1st day after the full moon of the month of *Pausha* (December-January) = 3 days.
3. No fish should be caught on the fast days—*Amāvasyā* or the day before new moon and the *Ashṭamī* or the eighth day during every fortnightly period of the moon = 12+24 = 36 days.
4. No tank fish (animals in the preserves of fishermen) should be taken during the above-noted days.

Recent observations have shown that the major carps of India breed during the rainy months from June-July to September-October and that spawning usually takes place on or about the full moon day, new moon day or eighth day of the moon. It will thus be seen that:

1. Aśoka's laws were very simple, applicable throughout his kingdom, and the prohibition periods were evenly spread over the whole of the year thus entailing no hardship either on the consumers or on fishermen.
2. Aśoka prohibited the sale of fish, even from tanks, on certain days and, therefore, the enforcement of his laws was very easy.
3. Aśoka's laws were based on the proper understanding of the migratory and spawning movements of the principal food-fishes of India.

I think I have convincingly shown that Aśoka's pillar edict V, dated 246 B.C., contains material which can even now be utilized for the advancement of fishery knowledge.

Having disposed off Chaudhuri's unjustified remarks about Suśruta and Aśoka, we may now make a very brief survey in a chronological order.

Indus Valley Civilizations.

Taking the archaeological records of the 3rd and 2nd millennium B.C. first, one finds that during the period of the Indus Valley Civilizations, between 4,000 and 5,000 years ago, fish formed a valuable item of diet and various fishing methods were in vogue.

The Nal Culture.—The earliest phase of these civilizations is represented by the Nal Culture. Nal is situated at a height of nearly 4,000 feet in the Baluchistan hills. Several funerary vases have such good fish paintings on them that the fish depicted can be readily identified (Hora, 1955, in press). Nearly all the common, present-day hill-stream fishes of the area, namely *Nemacheilus* van Hasselt, *Botia* Gray, *Glyptothorax* Blyth, *Tor* Hamilton and *Cyprinion* Heckel are represented in these drawings but there is one kind of fish, *Glyptothorax* Blyth, which is not now known to occur in the Baluchistan hills, though it is found in Persia on the one hand and throughout south-east Asia on the other. Its occurrence among the Nal pottery paintings is of great zoogeographical interest as it helps to bridge the gap partially between India and Persia. All the varieties of fish painted on Nal vases are of considerable food value. There is no record of the fishing methods that may have been practised at Nal, but damming of streams or poisoning of pools may have been practised as the hill tribes do today all over India and other parts of the world.

The Harappa Culture.—The next phase of the Indus Valley Civilizations is represented by the Harappa Culture where the paintings on pottery contain representations of fishes, fishing nets, baskets, etc. Sarkar (1954) has shown that ringstones, which may have been used as anchors for boats, are fairly common at Harappa.

The fish are presumably of the marine type, Carangids and Sticklebacks, showing that Harappa was a maritime town four to five thousand years ago and enjoyed a temperate climate. Angling, usually associated with freshwater fishes, was not much in vogue as only one fishing hook of a simple, non-barbed type is known so far from the excavations at Harappa.

The Mohenjo-daro Culture.—The Mohenjo-daro Culture is marked by the fact that fish motifs of ivory are very common; freshwater fish were used as food and angling would seem to have developed to a very high degree of perfection. The presence of a variety of net-sinkers at Mohenjo-daro shows that fishing by net was also a common practice. Some marine fish was also imported, as remains of the marine catfish *Arius* are known to have been excavated from kitchen mittens. This belief is strengthened by the fact that impression of a boat is found on a seal. The ringstones, used as anchors for boats, are also commonly found.

Whereas Harappa would seem to represent a maritime culture, Mohenjo-daro represents a riverine culture.

The Aryan Civilization

The Aryan Culture.—The Aryans, who are now stated to have destroyed the Indus Valley Civilizations, were probably not fond of fish to the same extent as the peoples of the Indus Valley Civilizations. Only a few fish names and allegorical references to the habits and fishing methods are found in the Vedas written about 1500 to 1000 B.C.

Ancient Hindu, Buddhist and Jain Cultures.—From 600 B.C. to 600 A.D., liking for fish as food seems to have increased considerably as the following records would show:

1. *Dharma-śāstras*, both Sūtras and Smṛitis, written between 600 B.C. and 200 A.D. show classification of fishes according to their food value and certain species are prohibited to be eaten (Hora, 1953: 66).

2. Jātaka stories and sculptures (Hora and Saraswati, 1955 and Hora, 1955*a* under publication), dated as 600 B.C. to 500 A.D., contain many references to fish and fisheries and fondness of fish as food, especially when taken with intoxicating liquors.

Early Jain sculptures also show a pair of fishes as auspicious symbols in Ayagapaṭṭas excavated at Mathura.

3. Charaka, Suśruta and other writers of old medical treatises discuss the food values of different fishes and their relative medicinal values.

4. Kauṭilya's *Arthaśāstra* gives an account of fishery management (Hora, 1948*a*).

5. Rāma during his visit to Pampā Sarovara is advised to eat *Cakratuṇḍa*, *Nalamīna* and *Rohita* (Hora, 1952*a*).

Bow and arrow were used for shooting fishes according to the *Rāmāyaṇa*.

Mediaeval Periods.—From the material so far investigated, it would appear that from the 7th century A.D. to the 11th century A.D., the fisheries declined. During the next 3 or 4 centuries, however, there was a revival of interest in fisheries once again as is evidenced by the following works:

1. Epigraphical records of the Pāṇḍya and Chola Kings regarding irrigation projects show revival of interest in fisheries (Hora, 1951).
2. *Matsyavinoda* written in 1127 A.D. is the first known treatise on the art of angling (Hora, 1951*a*).
3. *Bhāvaprakāśa*, a medical work, and a Persian encyclopædic work in MS., dedicated to Aurangzeb, deal with the food values of fishes.
4. Mughal emperors showed interest in the habits of Indian fishes (Hora, 1928).

British Period and after.—With the coming of the British and their lack of appreciation of inland fishery resources, there was a decline in fisheries once again till the Bengal famine of 1943 led to a revival of interest in the fish and fisheries of India.

From the above summary account, it will be clear that ancient India possessed considerable knowledge about the ecology and habits of Indian fishes and that various devices for fishing had been invented even during the remotest past of Indian history. A background knowledge of the past achievements can, no doubt, be very helpful in our modern development measures. It is hoped that efforts will be made on a national scale to unearth this valuable type of ancient knowledge for its proper assessment and utilization in the interest of the country.

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XVI. THE STREAMER MECHANISM AND THE SPARKING THRESHOLD

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Abstract

In finding the space charge field at some point in a gap subjected to overvoltage, we have assumed that the positive ions are uniformly distributed in a hemispherical volume under the diametral plane through that point parallel to the cathode surface. An expression for the field due to such positive ionic distribution has been obtained. The mutual repulsion of the electrons in the avalanche has also been taken into consideration in the derivation of the space charge field. The expression for the space charge field shows that the backward pull on the electron avalanche due to the positive ionic concentration may be appreciable, resulting in the checking of the electron avalanche as it proceeds towards the anode. When the electrons in the avalanche are thus checked at a certain distance from the cathode, some of the electrons drift back into the positive ionic concentration due to the mutual repulsion, decreasing thereby the backward pull on the electron avalanche and allowing the rest of the electrons to continue their journey towards the anode. At some further distance, the electrons may again be held up due to the backward pull of the positive ions, to be released once again to advance, when the backward pull is decreased due to the drift of some electrons back into the positive ionic concentration on account of mutual repulsion. The process may be repeated a number of times before the streamer formation. This accounts for the comparatively high values of formative time-lag observed by Fisher *et al.* It has also been possible to explain on this view the experimental results of these investigators on the formative time-lag for various pressures and percent overvoltages. The threshold potential has also been found and it has been shown that the streamer criterion for breakdown in a uniform field is quantitatively the same as the Townsend criterion. The theoretical value of the threshold is found to be half that given by Loeb and Meek and is in conformity with the recent experimental results.

1. Introduction

The streamer theory of breakdown, leading to filamentary sparks, was proposed by H. Raether and also independently by L. B. Loeb and J. M. Meek. It has been based on considerations of individual electron avalanches, the transition from an avalanche into a streamer and the mechanism of advance of streamers. The observations of Lawrence and Dunnington[1], the work of Raether[2] for uniform fields and that of Loeb[3] and his co-workers in corona studies and also the experimental studies of point-to-plane impulse breakdown by Allibone and Meek[4] and Meek and Saxe[5] have substantiated fairly well the streamer mechanism of spark breakdown. The criterion for streamer formation, first given by Meek[6], formed the quantitative basis for the streamer theory. The transition from an electron avalanche into a streamer was considered to take place when the radial field produced by the positive ions at the head of the avalanche was of the order of the externally applied field. Loeb and Meek[7] were able to obtain an expression for the

radial field E_r in the case of avalanches in air, so that the criterion for the onset of a streamer was given by

$$E_r = k.E \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

where E is the applied field and k ranges from 0·1 to 1·0*. A comparison between the calculated and the measured breakdown voltages showed good agreement up to a lower limit given by $p.\,d = 200$, where p is the pressure expressed in mm. and d, the gap length expressed in centimetres. For $p.\,d < 200$, it appeared that the breakdown was determined by the Townsend mechanism. The approach made by Raether to the problem of avalanche-streamer transition was essentially similar to that by Loeb and Meek, although there were certain differences in the values of the space-charge field produced by the avalanche. Petropoulos [8] attempted to derive a more accurate expression for the radial tip field of the avalanche than that given by Meek and Raether. According to him the limit of validity for the Townsend mechanism is $p.\,d \sim 500$ mm. Hg × cm. Loeb [9] also developed a more rigorous form of the Meek criterion by the inclusion of additional factors including the absorbing coefficient of the photo-ionizing photons and the ratio of the number of such photons to the number of positive ions in the avalanche head. Loeb and Wijsman [10], later, introduced a modification by considering the possibility of multiple electron avalanches developing simultaneously into the streamer tip. The modified sparking criterion is, however, very complex and on this basis the calculation of sparking voltage appears impracticable. Other contributions to the streamer theory regarding the space charge distribution have been made by Teszner [11], Szpor [12] and Fletcher [13].

Although Schade's [14] measurements of the formative times of the sparks lent support to the Townsend mechanism, there were considerable difficulties to explain by various modifications of the Townsend theory the small values (of the order of 10^{-7} sec. or less) of formative time-lag in gaps subjected to small overvoltages observed by severai workers.[15] The observed high speeds of formation of sparks were, however, found consistent with the streamer mechanism. Besides Raether [2], Fletcher [13] gave a rigorous treatment of the formative time-lag on the basis of streamer mechanism by considering in some detail the distribution of space charge in an avalanche. The subsequent work of Fisher and Bederson [16] and of Kachickas and Fisher [17], however, showed with smaller overvoltages quite large values of the formative time-lag in air, nitrogen and argon.

The formative time-lags in air observed by Fisher and Bederson [16] very close to the threshold for pressures greater than 200 mm. were of the order of 100 μ secs. For all the pressures in their experiments, the time-lags were found to decrease from 100 μ sec. as the percent overvoltage was increased, until at about 2% overvoltage the time-lag was about 1 μ sec. For a given percent overvoltage, the time-lag was, however, found to be linearly dependent upon plate separation, while it was, within limits, independent of pressure. The change in the number of initiating electrons did not materially alter the time-lag. This showed that the rôle of secondary electron emission from cathode by positive ion bombardment in the development of spark breakdown was precluded, thereby establishing the inadequacy of the Townsend mechanism. The curves relating time-lag with overvoltage obtained by Kachickas and Fisher [17] in the other gases were almost the same as those for air. The time-lags were also found unaffected by changes in the primary cathode photo-current. According to Fisher and Bederson [16], the long time-lags and their

* It is to be noted that the difference caused in the calculated breakdown voltage by a change in k from 0·1 to 1·0 is not large, the value varying only from 31·6 to 32·2 kV for the breakdown of a 1 cm. gap.

dependence on pressure and percentage overvoltage cannot be explained by the Townsend mechanism based on the emission of secondary electrons from the cathode by positive ion bombardment, as the time-lags decrease much more rapidly with increasing percent overvoltage than can be accounted for by the variation of positive ion velocities. The experimental results were explained as due to the enhancement of field intensified ionization caused by field distortion acting in conjunction with a photo-electric secondary process. Loeb [18] has put forward similar suggestions pointing out that above the threshold, positive ions accumulate in the gap and the resultant space-charge distortion enhances the time of development of a spark.

It is also significant that the experiments of Fisher *et al.* failed to find the transition region from the streamer mechanism to the Townsend mechanism, as also the experiments of Gänger [19]; and that in uniform fields the threshold was set by the conventional Townsend criterion, $r \cdot \exp(\alpha . d) = 1$, where α and r are the Townsend coefficients, and d is the sparking distance.

In the present paper we have attempted to explain the experimental results of Fisher *et al.* on the comparatively large formative time-lags and their dependence on pressure and percent overvoltage in a different way by introducing certain modifications in the expression for the space charge field. We have also shown how in a uniform field the criterion of streamer formation is given quantitatively by the Townsend criterion, thus removing the paradoxical situation.

2. Considerations leading to a modified expression for the space charge field

The conditions necessary for streamer formation are as follows:

(i) Sufficient high-energy photons must be created in the initial avalanche to ionize some of the gas atoms or molecules.

(ii) These photons must be absorbed to produce ionization in adequate proximity to the streamer tip.

(iii) The space charge field at the rear of the avalanche tip should be large enough to give adequate secondary avalanches in the enhanced field.

We have already referred to the idealized quantitative threshold developed by Loeb and Wijsman [10] on the basis of the above conditions. Here, however, we have considered the original Meek criterion and have made use of a modified expression for the tip field due to positive ion concentration in the gap, the modification being due to the following considerations:

(*a*) In finding the effect of the electrostatic attraction of the positive ionic space charge on the electron avalanche, Loeb and Meek [7] assumed the positive ions to be uniformly distributed in a spherical volume of Raether's radius, r, and calculated the electrostatic field at the surface of the sphere. On the basis of such calculation, it was shown that the space charge field was given by

$$X_1 = \tfrac{4}{3} \cdot \frac{e\alpha \exp(\alpha x)}{r} \qquad \text{(2)}$$

where x = distance from the cathode,
e = electronic charge,
α = Townsend's first coefficient,
and r = Raether's radius.

Accordingly in the case of air at atmospheric pressure, the backward pull due to positive ions on the electron swarm near threshold is insufficient to check the progress of the avalanche ever in its journey towards the anode.

There is, however, no justification for assuming the positive ions to be uniformly distributed in a spherical volume of radius r. The positive ions are, in reality, distributed in the lower half of the sphere of radius r (see Fig. 1). The upper half of the sphere, shown by dotted line, has no positive ions at all. We have, therefore, considered that the positive ions are distributed in the hemisphere under the diametral plane parallel to the cathode surface.

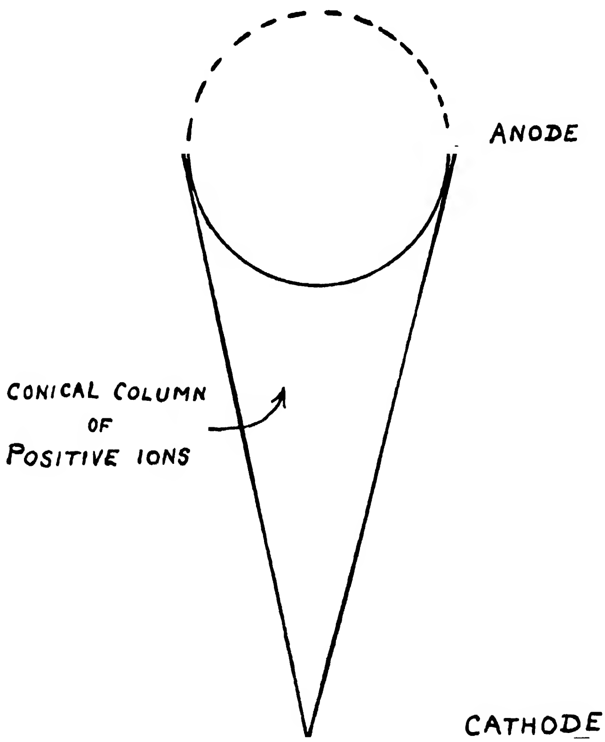

FIG. 1

(*b*) As the electron swarm moves towards the anode, the mutual repulsion of the electrons, especially near the anode where the concentration is considerable, has been taken into consideration in the derivation of the space charge field.

3. Modified space charge field and its effect on the electron avalanche

Investigating the effect of the positive ionic field when the ions are in the lower half of the sphere, it has been shown (see Appendix A) that the field on the diametral plane parallel to the cathode surface is given by

$$X_1' = \frac{2Nre}{3}\sqrt{4+\pi^2} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

where N = positive ionic density,
r = radius of the hemisphere,
and e = positive ionic charge.

Since the positive ion density at distance x from the cathode is given by

$$N = \frac{n_0 \alpha \exp(\alpha x)\, dx}{\pi r^2\, dx} = \frac{n_0 \,.\, \alpha \,.\, \exp(\alpha x)}{\pi r^2}$$

where n_0 is the number of initiating electrons, we have

$$X_1' = \tfrac{2}{3}\, n_0 e \alpha \,.\, \frac{\exp(\alpha x)}{\pi r} \sqrt{4+\pi^2} \qquad \ldots \quad \ldots \quad \ldots \quad (4)$$

This gives the backward pull due to positive ions on the electron avalanche.

It has also been shown (see Appendix B) that the field at the apex of such a hemisphere is given by

$$X_0 = \tfrac{2}{3}\, \pi N r e \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

If we assume that the density of the electron in the avalanche is appreciable, the mutual repulsion amongst the electrons would become significant and we can express it in the form of an increase in the backward pull. Consequently we put X', the effective field operating on the electron avalanche, equal to

$$X' = K \,.\, X_1' = K \,.\, \tfrac{2}{3} \cdot \frac{n_0 e \alpha \exp(\alpha x)}{\pi r} \cdot \sqrt{4+\pi^2} \qquad \ldots \quad \ldots \quad \ldots \quad (6)$$

where $K > 1$.

As the electron avalanche proceeds towards the anode, the electrostatic pull due to the positive ions increases and it is evident that at a certain distance x from the cathode, the progress of the electron swarm would be checked when

$$X' = X = K \,.\, \tfrac{2}{3} \cdot \frac{n_0 \,.\, e \alpha \exp(\alpha x)}{\pi r} \cdot \sqrt{4+\pi^2}$$

where X is the applied field. On account of mutual repulsion, however, some of the electrons from the electron avalanche would migrate to the positive ionic space charge, thereby decreasing the effective backward pull on the electrons due to positive ions. The rest of the electrons of the electron swarm would, therefore, be able to move in the applied field and create new ion pairs by collision. When again the positive ion density is built up to a value large enough to check the progress of the electron avalanche, there will be again the holding back of the avalanche followed by their migration towards the positive ionic column and the whole process would be repeated again. When, however, electrons in the avalanche reach the anode and are absorbed by it, the positive ion tip field would attract photo-electrons and electron avalanches and the breakdown would proceed according to the conventional streamer mechanism.

It is to be noted that the advance of the electron avalanche towards the anode is of the nature described above before the streamer is formed, so that the formative time of the spark is increased by this kind of electron movement. As the condition of streamer formation, for a given value of the applied field, is determined by the density of positive ion concentration in the gap, the tip velocity of the streamer is not likely to be affected by the nature of movement of the electron avalanche prior to the streamer formation. The velocity of the cathode-directed positive streamer and that of the anode-directed negative streamer which were found by Raether [19] and others [20] to be of the order of 10^8 and 10^7 cm./sec. respectively are not really contradictory to our view regarding the nature of advance of the electron avalanche before the streamers are actually formed.

4. Calculation of the Threshold Potential

The formation and propagation of the streamer require that the field at the apex of the hemisphere due to the positive ionic charge should be comparable to the applied field. For threshold, therefore, we equate the field at the apex of the hemisphere containing positive ions (at a distance $x = d$ from the cathode, where d is the gap length) to kX where X is the applied field and k a constant lying between 0·1 and 1·0. Therefore we have

$$X_0 = kX = \tfrac{2}{3}\pi Nre \quad \ldots \quad (5)$$

But

$$N = \frac{n_0\alpha \exp(\alpha x)}{\pi r^2}$$

Therefore

$$X_0 = \tfrac{2}{3}\frac{n_0 e\alpha \exp(\alpha x)}{r} \quad \ldots \quad (7)$$

Substituting in equation (7), the value of r calculated by Loeb and Meek[7] in terms of gap length d and pressure p, *viz.*

$$r = \left(0{\cdot}133\frac{d}{p}\right)^{\frac{1}{2}}$$

we get

$$X_0 = \frac{2}{3}\cdot\frac{n_0 e\alpha \exp(\alpha d)}{\left(0{\cdot}133\frac{d}{p}\right)^{\frac{1}{2}}} = kX \quad \ldots \quad (8)$$

This equation can also be put in the form

$$\frac{2}{3}\cdot\frac{n_0 e}{k}\cdot\frac{(\alpha/p)}{(X/p)}\cdot\frac{\exp(\alpha d)}{\left(0{\cdot}133\frac{d}{p}\right)^{\frac{1}{2}}} = 1 \quad \ldots \quad (9)$$

Putting

$$\gamma = \frac{2}{3}\cdot\frac{n_0 e}{k}\cdot\frac{(\alpha/p)}{(X/p)}\cdot\frac{1}{\left(0{\cdot}133\frac{d}{p}\right)^{\frac{1}{2}}}$$

we get $\gamma \exp(\alpha d) = 1$, as the condition for breakdown. It is of the conventional Townsend form.

An estimate of γ in the streamer mechanism formula for the sparking criterion can be obtained from (9) by putting the experimental values of (α/p), (X/p), d and p for air as given by Townsend[21]. When $p = 1520$ mm., $(X/p) = 39{\cdot}2$ volts/cm., $(\alpha/p) = 0{\cdot}0129$, the calculated value of γ is given by

$$\gamma = 1{\cdot}07\times 10^{-9}\times\frac{n_0}{k}$$

Putting $n_0 = 1$ and $k = {\cdot}5$, we get

$$\gamma = 2{\cdot}14\times 10^{-9}.$$

Townsend's experimental value of γ for air, as obtained from $e^{-\alpha d}$, under the same conditions is 3×10^{-9}. For other values of (α/p), (X/p) and p, the calculated value of γ in the streamer mechanism criterion is more or less of the same order as the experimental value given by Townsend. The streamer criterion for breakdown may, therefore, be regarded as quantitatively the same as the Townsend criterion.

5. Interpretation of the experimental results of Fisher *et al.*

The comparatively high values of the formative time-lag observed by Fisher *et al.* have already been explained. We shall now consider how the formative time-lag should depend on pressure and percent overvoltage.

It has been shown (see Appendix C) that the distance x from the cathode where the progress of the electron avalanches is checked is approximately given by

$$\frac{\frac{4}{9}k^2e^2n_0^2\frac{(4+\pi^2)}{\pi^2}\cdot\frac{(\alpha/p)^2}{(X/p)^2}\cdot\frac{1}{0\cdot133}}{\left[\frac{1}{p}-\frac{4}{9}k^2e^2n_0^2\cdot\frac{(4+\pi^2)}{\pi^2}\cdot\frac{(\alpha/p)^2}{(X/p)^2}\cdot\frac{2\alpha}{0\cdot133}\right]} \quad \ldots \quad \ldots \quad \ldots \quad (10)$$

The numerator in the expression for x is very small and hence the value of x would vary extremely slowly with the pressure, p, and it can be said that within certain limits, the variation of p will not affect the value of x substantially. The time-lag can thus be regarded as independent of pressure within limits. It is also evident from (10) that x is a function of $(\alpha/p)/(X/p)$ and hence if the parameters x, α and p are kept constant, the value of x would also remain constant, even if the plate separation d is varied. Since the time-lag is proportional to the number of times (*viz.* d/x) the electron avalanche is checked in its journey to the anode, it is evident that the time-lag should increase proportionately with the increase of plate separation. This is in conformity with the experimental results of Fisher and Bederson [16].

6. Conclusions

The conclusions which may be drawn from the modified expression for the field due to the positive ionic concentration in a gap subjected to overvoltage are enumerated below:

(1) The threshold potential is lowered to half the theoretical value originally given by Loeb and Meek, as can be seen from the equations (2) and (5). That the theoretical values of the threshold potential given by Loeb and Meek are definitely higher than the experimental values can thus be explained.

(2) The condition for breakdown in a uniform field according to the streamer mechanism is quantitatively the same as the Townsend criterion.

(3) The comparatively high values of the formative time-lag and its dependence on percent overvoltage and pressure, as observed by Fisher *et al.* can be interpreted.

(4) When the electrons in the avalanche are momentarily checked in their journey towards the anode, some of them drift towards the rear on account of their mutual repulsion, forming thereby a conducting region containing positive ions and electrons. As the process may be repeated, it is expected that even before the streamer formation, some regions in the positive ionic column will already be in a conducting state. Under such a condition, the photon-density required for the streamer formation need not be very high.

Appendix A

Calculation of the field at some point in the gap when the positive ions are uniformly distributed in a hemisphere under the diametral plane through that point parallel to the cathode surface.

Let O be the origin of co-ordinates (see Fig. 2), OX be the line through the centre C

of the diametral plane and OZ be perpendicular to this plane. Thus using polar co-ordinates r, θ and ϕ, the attraction Z along OZ

$$\frac{r^2 \sin\theta \,.\, d\theta \,.\, d\phi \,.\, dr}{r^2} \,.\, N \cos\theta$$

where $N =$ density of the charge.

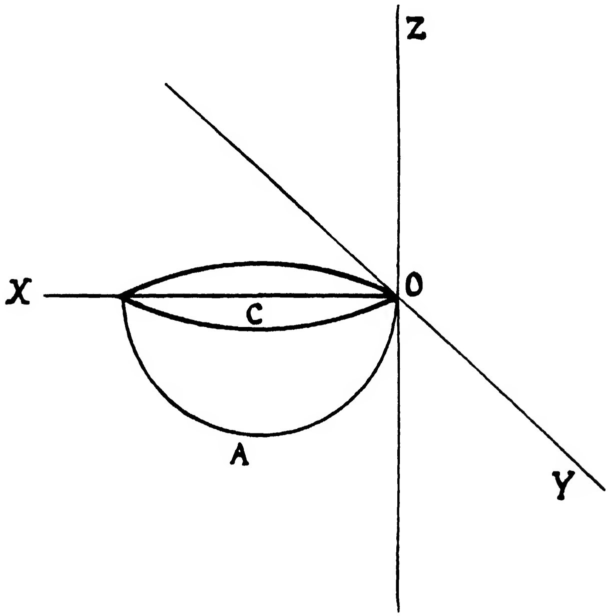

Fig. 2.

If a is taken as the Raether's radius, then the equation of the surface of such radius is given by

$$(x-a)^2+y^2+z^2 = a^2$$
$$\text{or} \quad r^2 = 2ax = 2ar \cos\phi \,.\, \sin\theta$$
$$\text{or} \quad r = 2a \cos\phi \,.\, \sin\theta$$

Thus the limits for r are 0 and $2a \cos\phi \sin\theta$. The limits for θ are 0 and $\frac{\pi}{2}$ and those for ϕ are $-\frac{\pi}{2}$ and $+\frac{\pi}{2}$.

Hence $$Z = N \int_0^{\frac{\pi}{2}} \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \int_0^{2a \cos\phi \sin\theta} \sin\theta \,.\, \cos\theta \,.\, d\theta \,.\, d\phi \,.\, dr$$

$$= N \int_0^{\frac{\pi}{2}} \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} 2a \cos\theta \,.\, \sin^2\theta \,.\, \cos\phi \,.\, d\theta \,.\, d\phi$$

$$= \frac{4}{3} aN$$

The component attraction X towards the centre

$$= \int_0^{\frac{\pi}{2}}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}\int_0^{2a\cos\phi\sin\theta} \frac{N\,.\,dr\,.\,r\,d\theta\,.\,r\sin\theta\,.\,d\phi}{r^2}\,.\cos\phi\sin\theta$$

$$= \frac{2\pi Na}{3}$$

By symmetry, the attraction along OY vanishes. Hence resultant attraction is

$$\frac{2\pi Na}{3}\sqrt{4+\pi^2}$$

Appendix B

Calculation of the attraction at the apex of the hemisphere of uniformly distributed positive ionic charge.

Let the origin of co-ordinates be at A. Then the equation of sphere is

$$x^2+y^2+(z-a)^2 = a^2$$

$$\text{or}\quad 2az = r^2 = 2ar\sin\theta$$

$$\text{or}\quad r = 2a\sin\theta$$

Therefore the attraction towards CZ is

$$\int^{\frac{\pi}{2}}\int_{\frac{\pi}{2}}^{\frac{\pi}{2}}\int_0^{2a\sin\theta} \frac{N.\,dr.\,r\sin\theta\,.\,r\,d\theta\,.\,d\phi}{r^2}\cos\theta = \frac{2\pi aN}{3}$$

Appendix C

Calculation of the distance where the electron avalanche is checked by the backward pull exerted by the positive ions.

Equation (6) gives $\qquad X = k.\,\dfrac{2}{3}\cdot\dfrac{n_0\alpha e\exp(\alpha x)\sqrt{4+\pi^2}}{\pi r}$

The value of r given by Loeb and Meek [7] is $r = \left(0{\cdot}133\,\dfrac{x}{p}\right)^{\frac{1}{2}}$

Therefore $\qquad X = k.\,\dfrac{2}{3}\cdot\dfrac{n_0 e\alpha\exp(\alpha x)\sqrt{4+\pi^2}}{\pi\left(0{\cdot}133\dfrac{x}{p}\right)^{\frac{1}{2}}}$

or $\qquad \dfrac{x}{p} = \dfrac{4}{9}k^2n_0^2e^2\dfrac{\exp(2\alpha x)}{0{\cdot}133}\cdot\dfrac{(\alpha/p)^2}{(X/p)^2}\cdot\dfrac{4+\pi^2}{\pi^2}$

or $\qquad \dfrac{x}{p} = \dfrac{4}{9}k^2n_0^2e^2\cdot\dfrac{1+2\alpha x}{0{\cdot}133}\cdot\dfrac{(\alpha/p)^2}{(X/p)^2}\cdot\dfrac{4+\pi^2}{\pi^2}$, for small values of αx.

or $\qquad x\left[\dfrac{1}{p}-\dfrac{4}{9}k^2n_0^2e^2\cdot\dfrac{(\alpha/p)^2}{(X/p)^2}\cdot\dfrac{4+\pi^2}{\pi^2}\cdot\dfrac{2\alpha}{0{\cdot}133}\right] = \dfrac{4}{9}k^2n_0^2e^2\cdot\dfrac{(\alpha/p)^2}{(X/p)^2}\cdot\dfrac{4+\pi^2}{\pi^2}\cdot\dfrac{1}{0{\cdot}133}$

or

$$x = \frac{\frac{4}{9} k^2 n_0^2 e^2 \frac{(\alpha/p)^2}{(X/p)^2}}{\left[\frac{1}{p} - \frac{4}{9} k^2 n_0^2 e^2 \left\{(\alpha/p)^2/(X/p)^2\right\} \cdot \frac{4+\pi^2}{\pi^2} \cdot \frac{2\alpha}{0 \cdot 133}\right]}$$

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XVII. INDUCED CONDUCTIVITY OF METAL—SEMICONDUCTOR CONTACTS

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INTRODUCTION

The property of the diminution of resistance of certain poor metallic contacts under the influence of Hertzian waves was first utilized by Lodge[1], who called such a detector a 'coherer'. The detector may be made by enclosing iron filings between metallic electrodes in a glass tube. When an a.c. voltage is applied across such a tube, the filings 'cohere' in such a way that the resistance between the electrodes is momentarily more or less unidirectional, but ceases to rectify as soon as the filings are in close contact. Hence, for continuous reception, such a detector must be tapped continuously in order to 'de-cohere' the filings. Solari made the Marconi coherer self-decohering by replacing the filings by a small pellet of mercury. Mention may also be made of the Lodge-Muirhead wheel coherer which automatically decoheres as it rotates. Guthe and Trowbridge[2] showed that the current-voltage characteristic of a coherer made of small metallic balls and continually tapped does not follow Ohm's law, and consequently rectification can occur. They obtained the relation $V = A(1-e^{-BI})$, where A and B are constants. Furthermore, a slight movement of the filings was observed to take place when the cohesion occurred with the incidence of electro-magnetic waves.

Of the various attempts made to explain the action of contact-sensitiveness, Lodge's theory of coherence had been the most suggestive. In fact, Lodge's observation of the welding of two metallic spheres by powerful oscillatory discharge in the neighbourhood, apparently lent much support to the theory of electric welding, which explains in a simple manner the diminution of contact resistance of various metallic filings when subjected to strong electric field variation. On this theory it follows that all imperfect contacts should exhibit a diminution of resistance when subjected to electric radiation.

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However, in carrying out a systematic investigation of the contact-sensitiveness of various metals including K, Na, Li, Mg, Ln, Cd, Bi, Sb, Fe, Ni, Co, Mn, Cr, Al, Sn, Pb, Tl, Mb, Pt, Pd, Os, Rh, As, Cu, Ag, Au and U, Bose[3] found that there were substances which exhibited an increase of resistance. He showed that the effect of increase of contact resistance is not an exceptional or isolated phenomenon, but is as normal and definite under various conditions as the diminution of resistance noticed in the case of iron filings. He divided the cohering substances into two cateogories: positive and negative. Substances were regarded as positive when electric oscillations produced an increase of conductivity or diminution of resistance, and negative when the contrary effect was produced. Furthermore, he obtained the astonishing result about the change of sign of response in the cohering receiver due to a variation of intensity of radiation.

For example, a receiver made of freshly powdered arsenic (a negative substance) exhibited a moderate increase of resistance when placed in the neighbourhood of a

radiation. As the radiator was moved further and further, the increase of resistance became less and less. When the distance was increased to 25 cm. the action was reduced to zero; at a distance of 30 cm., there was an actual diminution of resistance, showing that 25 cm. was, in this case, the critical distance. Similarly, a feebly positive substance, like osmium, exhibited a diminution of resistance when the radiator was close to the receiver, and an increase of resistance when the radiator was beyond the critical distance. In order, therefore, to avoid confusion, Bose[4] decided to call the effect due to strong intensity as the normal action. He also verified the sign of normal action, wherever possible, by obtaining a reverse action under feeble intensity of radiation.

Bose also found an anomalous behaviour in the case of silver, which, when subjected to radiation, exhibited sometimes an increase, and at other times a decrease, of resistance. The difficulty in this case could not be explained on the supposition of variations of radiation intensity, as the anomaly persisted even when the intensity of radiation was maintained uniform by keeping the radiator at a fixed distance.

In order to explain these actions, Bose[5] assumed the following hypotheses:

(1) That electric radiation produced molecular change or allotropic modification in a substance.

(2) That, starting from the original molecular condition *A*, the effect of radiation is to convert it, to a more or less extent, into the allotropic modification *B* (the latter condition being designated as the 'radiation effect').

(3) That the ultimate loss of sensitiveness, known as 'fatigue', is due to the presence of the radiation product, or strained variety *B* along with the *A* variety, the opposite effects produced by the two varieties neutralizing each other.

He also subdivided the principal types of coherers into three groups.

(*a*) Substances in which the *B* state is unstable under given conditions. The *B* state persists only during the action of radiation, the substance relapsing into the original condition on cessation of radiation. Two alternative cases are possible depending upon whether the substance is positive or negative. The latter case is exemplified by potassium, where there is immediate self-recovery.

(*b*) Substances in which the radiation product is somewhat stable: the successive conversions from *A* to *B* and from *B* back to *A* are supposed to be complete. Magnesium conforms to this class approximately.

(*c*) Class of substances where conversion from one state to another is not complete. Here again, one gets two subdivisions, owing to the distinction between positive and negative substances.

It was also found that in the 'fatigued' condition, the positive substance as a whole was more conducting while the negative substance was, on the whole, less conducting than in the fresh condition.

Bose[6] found that heating or a mechanical disturbance like tapping produced restoration of sensitiveness of the fatigued substances—the positive class registering an increase, and the negative class a decrease of resistance. He suggested that tapping restored the sensitiveness *not* by the separation of the electrically-welded particles (in which case tapping ought to have produced an increase of resistance in *both* classes of fatigued substance) but by removing the strain in *B* and thus converting it into *A*. The effect of electric radiation was thus to produce rearrangement of atoms and molecules in a substance. He showed experimentally the 'curious molecular hesitation at critical times as to the choice of structure to be adopted, and of the molecular inertia by which the

newly-formed structure is carried beyond the position of stability and the subsequent creeping back to the more stable position'.

Furthermore, it was effectively shown that the seat of sensitiveness is confined mainly to the surface layer of the sensitive substance, and that the nature of the substratum had little or no effect on the sensitiveness. It was also noted that pressure had a pronounced effect on molecular response. Moderate pressure increased the sensibility but too great an increase of pressure caused a loss of sensibility. Moreover, pressure variation sometimes caused a reversal of response. Another very curious phenomenon met with was the opposite effect of radiation below and above the critical intensity. In either case reversal of response was observed.

Thus, Bose by his highly ingenious experiments gathered an amazing mass of valuable results which could not be satisfactorily explained by any contemporary theory. Moreover, owing to the rapidity with which wireless science has progressed, new methods of detection superseded the old coherer, before the implications of the latter were fully understood.

Recent development

In recent years, however, the interest in the study of small area contacts has been revived on account of the discovery of the crystal amplifier or transistor. Large area contacts between metals and semi-conductors have been studied over a period of years, and the theory of such contacts is in fair agreement with experiment. In general, however, there are so many complicating factors, which so far have not been taken into account, that detailed comparison of theoretical and experimental results over wide ranges of current and voltage is not possible. The work on silicon and germanium was undertaken in the hope that some of these factors could be eliminated, as these materials are simpler than most semi-conductors. Their importance in the manufacture of crystal rectifiers for frequency conversion and detection also furnished a strong incentive in the investigation of their properties. It was this investigation—concentrating chiefly on the properties of space charge barrier layers at free surfaces of semi-conductors—that led to the discovery of the transistor.

It is in the context of the theory of contact between a metal and semi-conductor, that we shall attempt to explain many of Bose's experimental results.

Brief outline of theory

In order to give a coherent picture, we give here a brief outline of the semi-conductor theory, which is due to Wilson.[7] The possible energy levels of an electron in a crystal may be divided into bands, which are again separated by bands of forbidden energy. Wilson supposes that in a semi-conductor, as in an insulator, at the absolute zero of temperature all the allowed bands are either completely full or completely empty, so that the crystal cannot carry any current. In a semi-conductor, however, as the temperature is increased, some electrons are raised into the lowest empty band of allowed levels (the conduction band). These electrons give to the crystal its conductivity.

There are, however, two classes of semi-conductors—intrinsic and extrinsic. An intrinsic semi-conductor is one which conducts in the pure state; here electrons are raised into the conduction levels from the normally full band. Most semi-conductors, however, owe their conductivity to the presence of impurities in solid solution, and the actual value of the conductivity is very sensitive to the amount of these impurities present. The theory assumes that the energy required to bring an electron from an impurity centre into the

conduction band is considerably less than that required to bring it from the full band of the pure substance, so that the conduction is mainly due to electrons removed from the impurities.

Semi-conductors in which the current is carried by electrons raised from normally occupied impurity levels into the conduction band are known as 'excess', 'normal' or '*n*-type' semi-conductors (extrinsic).

In another type of extrinsic semi-conductor, the conductivity is due to the presence of empty impurity levels lying above the full band. If electrons are raised from the full band into the impurity levels, the vacancies which remain act like positive charge-carriers and are called 'positive holes'. Substances in which the current is carried in this way are called 'deficit', 'abnormal', or '*p*-type' semi-conductors. Fig. 2 shows the energy levels of the two types of extrinsic semi-conductor. It is interesting to recall that Bose also classified his coherers into two classes—positive and negative.

Germanium becomes an intrinsic conductor at temperatures of the order of 500°C and higher. At ordinary temperatures, it is an *n*-type or *p*-type semi-conductor, depending upon the nature of impurity which predominates.

The number of electrons in the conduction band or holes in the full band at a given temperature can be calculated quite readily. For *n*-type materials the number of electrons in the conduction band is

$$n = C_1\sqrt{N}\, e^{-\frac{1}{2}\Delta E/KT}$$

where N is the number of impurity centres all of which at the absolute zero of temperature contain trapped electrons.

ΔE, energy gap between impurity levels and conduction band.

K, Boltzmann's constant ($= 1{\cdot}38\times 10^{-16}$ erg. per °C)

T, absolute temperature.

C_1, a quantity which varies slowly with temperature compared with the exponential term and may be considered constant.

A similar formula applies in the case of hole conduction.

The activation energy ΔE is of the order of room temperature value of KT ($\simeq \frac{1}{40}$ eV), for both types of impurity centre so that practically all impurity centres are dissociated (*i.e.*, *n*-type centres have lost their electrons and *p*-type centres have all gained electrons) at room temperature. The impurity centre activation energy ΔE and the sign of the predominant charge carriers in most semi-conductors can be determined by conductivity and Hall effect measurements at ordinary temperatures. The energy gap between the conduction band and the top full band can be determined by similar measurements at high temperatures where intrinsic conductivity occurs. For germanium, this gap (E in Fig. 2) is about 0·75 eV.

Apart from the elements, selenium, germanium and silicon, most semi-conductors are metallic oxides, sulphides, or silicates. In the present investigation, however, we are mostly concerned with metallic oxides.

Oxidation of metals

Recent experimental work indicates that many metals, perhaps all of which oxidize readily, show very similar behaviour when exposed to oxygen at a sufficiently low temperature. Oxidation is initially extremely rapid, but after a few minutes or hours the rate drops to very low or negligible values, a stable film 20–100 Å thick being formed. An explanation of this behaviour was first given by Cabrera and Mott.[8] It is based on

the hypothesis that a strong field is set up in the oxide film due to a contact potential difference between metal and absorbed oxygen, which enables metal ions to move through it without much help from temperature. The theory gives a logarithmic growth law of the type

$$1/X = A - \ln t$$

X being the thickness in time t.

Thus a stable film will grow until it reaches a limiting thickness and will then stop if the temperature is low enough for the following conditions to be satisfied:

(*a*) Metal ions cannot cross the film without the aid of a strong electric field, which only exists in thin films;

(*b*) In the case of films compressed to fit the metal substrate, the temperature at which crystallization occurs is not reached.

For metals of which the original oxide film is not fitted to the metal substrate (aluminium), and perhaps for recrystallized films too, another intermediate region can be recognized. In this case, the temperature is high enough for ions to diffuse without the help of a strong field, but yet not sufficiently high for the oxidation to conform to the parabolic law: $X^2 = 2At$.

In the latter case, at still higher temperatures, either metal or oxygen is soluble in the oxide. Local thermodynamic equilibrium exists at the metal-oxide and the oxide-air interfaces. The concentrations of metal (or oxygen) at the two faces are therefore different; metal or oxygen consequently diffuses through the oxide layer under a concentration gradient which is proportional to $1/X$. Oxides such as those of Zn and Al do not dissolve oxygen; they can, however, dissolve metal, thereby becoming 'excess' or *n*-type semi-conductors. Oxides such as those of copper and iron dissolve oxygen, thus becoming 'deficit' or *p*-type semi-conductors. Nevertheless, it is not the oxygen which diffuses, but the metal, as has been proved by the use of tracers in the case of copper by Bardeen, Brattain and Shockley.[9]

Thus, most metals form oxide layers and become impurity semi-conductors. In such semi-conductors as TiO_2 and ZnO, the conductivity is produced by partial reduction, the impurity being thus excess metal. It is believed that the metal is present in the following form: the metal ion Ti^+ or Zn^+ is dissolved interstitially in the oxide lattice, and again the electron is held in the field of this positive charge. On the other hand, in oxides (such as Cu_2O) which acquire their conductivity by reduction, the impurity centre is a site from which either Cu^+ is missing, or an electron is missing from one of the Cu^+ ions (positive hole). Since these produce singularities of opposite sign, the energy is lowest when they are in adjacent sites. As the temperature is raised, however, they can separate and the positive hole can move through the lattice. As a matter of fact in Cu_2O, the cuprous ions Cu^+ is with the configuration $(3d)^{10}$. If, now, an electron were removed from one of the Cu^+ ions forming Cu^{++} ion $(3d)^9$, then this hole could be transferred by electron exchange through the lattice. It is a deficit semi-conductor.

A particularly interesting case is provided by Fe_3O_4. It consists of ferric and ferrous ions in the ratio 2: 1, $Fe^{2+}\ Fe_2^{3+}\ O_4^{2-}$. Thus it should show almost metallic conductivity, and in fact at room temperature, $\sigma \simeq 20$ mho/cm.

If, however, a semi-conductor contains in the same volume impurities of the two types, they cannot activate it for excess or deficit semi-conduction at the same time. A material can show hole and electron conduction at the same time, only if the temperature is high enough for it to behave as an intrinsic semi-conductor. This appears to happen for PbS.

Barrier layer theory.

The rectifying and amplifying properties of semi-conductors when associated with metals result from the characteristics of semi-conductor layer immediately adjacent to the metal. In some cases, they also depend upon the work function of the metal itself. In order to get through this layer, an electron must have an energy larger than the average energy of electrons in the metal or in the conduction band of the semi-conductor. We may describe the situation by saying that an energy barrier exists at the contact between the metal and semi-conductor. For this reason, the surface layer of the semi-conductor is called the 'barrier layer'. It is also sometimes referred to as a 'space charge layer', because the barrier is due to an excess charge spread through the layer.

The electron energy structure in a metal is, as in the case of an insulator or semi-conductor, divided into bands of allowed energies separated by forbidden regions. The important difference is that the upper band containing electrons is only partially full, so that electrons can easily exchange their energies under a disturbing influence, *i.e.*, there are plenty of new energy states for them to occupy. Such a disturbing influence may be an applied electric field. At the absolute zero of temperature the electrons in the metal occupy the lowest states in the band. The surface of these occupied states (S in Fig. 1)

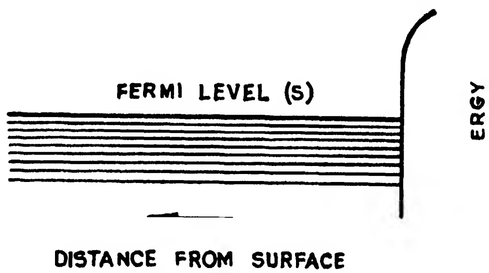


Fig. 1. Simplified picture of energy levels in a metal.

is defined as the Fermi level at the absolute zero of temperature. At higher temperatures the Fermi level rises slightly. The change at ordinary temperatures is, however, relatively small, and for practical purposes the Fermi level may be assumed to remain at S.

The term 'Fermi level' is also applied to semi-conductors. Probably the simplest way of considering this case is to regard the Fermi level as a sort of average energy level from which electrons jump to the conduction band and to which the electrons jump from the full band.

In an n-type extrinsic semi-conductor, the former process can take place more easily and the Fermi level is closer to the conduction band (Fig. 2a). If the number of donors

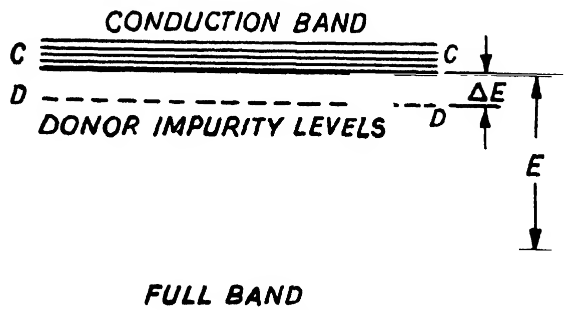


Fig. 2a.

is much larger than the number of acceptors and excitation from full band to the conduction band is negligible, the Fermi level is approximately half-way between the donor energy level and the conduction band.

In a p-type extrinsic semi-conductor the Fermi level is closer to full band than to the conduction band (Fig. 2b), indicating that holes are more easily formed than electrons

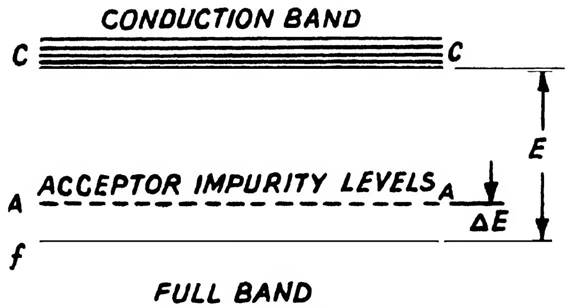


Fig. 2b.

and its exact position is decided by considerations similar to those outlined above for n-type materials. In an intrinsic semi-conductor excitation of an electron from full to conduction band produces an electron in the conduction band and a hole in the full band simultaneously and the Fermi level is half-way between the two bands. The above results, together with those of more complicated cases, are derived by Fowler.[10]

The importance of the Fermi level for our purpose arises from the fact that when the two materials are brought together, the potential between them must adjust itself so that the energies of their Fermi levels are the same. The point from which these energies are measured has not so far been defined, but it will be apparent that a common energy zero is the energy of an electron at rest outside, and beyond the influence of, the surfaces of materials. The difference of this energy and that of the Fermi level of one of the materials is called the work function of the material and is the energy required to remove an electron from it. The position when a metal and a semi-conductor are brought together is shown in Fig. 3(a). In the final equilibrium position the Fermi energies μ_m and μ_s must be the same and until this condition is established electrons will flow from the semi-conductor to the metal since $\mu_s > \mu_m$. As a result, a positive space charge due to the positively charged donors will be created in the layer of semi-conductor immediately adjacent to the metal, and a corresponding number of electrons will be held at the surface of the metal by the attraction of this positive space charge. An electrical 'double layer' of this type has the effect of lowering the Fermi level in the semi-conductor so that the final potential energy diagram of an electron will be as shown in Fig. 3(b). The Fermi levels of the metal and semi-conductor are the same, but a 'natural' potential barrier exists between them. If the contact between the metal and semi-conductor is very intimate, the height of this barrier may not be equal to χ_m as shown in Fig. 3(b) since if the distance AB is very small, electrons can penetrate the thin section BC of the barrier in spite of the fact that they have not sufficient energy to surmount the barrier. This phenomenon is explained by a 'quantum-mechanical tunnel effect'. It serves to reduce the height of the barrier between metal and semi-conductor to the value ϕ_0. The above type of barrier, which has been discussed in detail by Schottky [11] and is called a 'natural' one, may be modified in various ways. There may, for instance, be an insulating layer between metal and semi-conductor as in the case of commercial copper-oxide rectifier. The insulating layer is believed to be

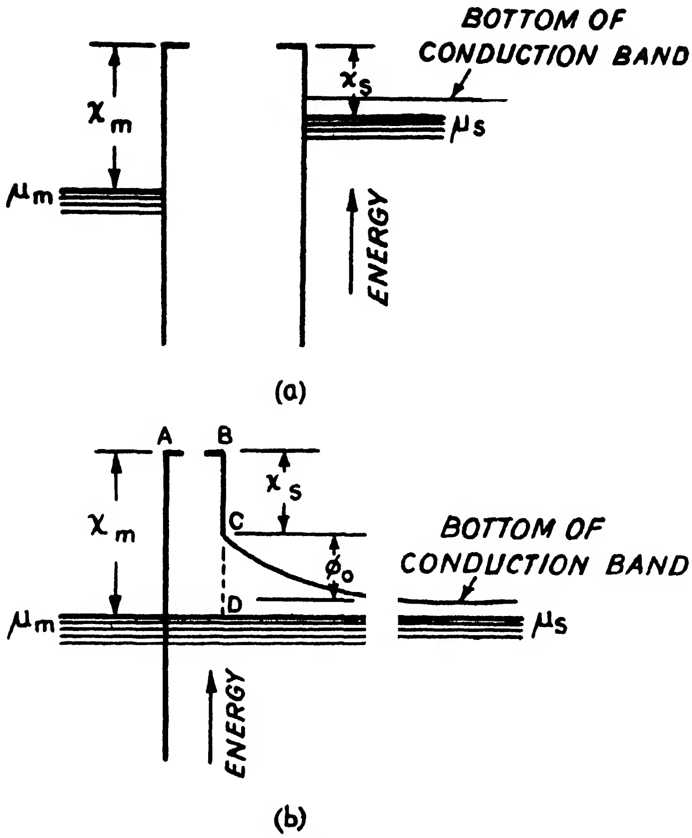


FIG. 3.

cuprous which differs from the bulk semi-conductor only in that it lacks impurity centres. For copper-cuprous oxide rectifiers, the value of ϕ is 0·7 eV. It seems generally to be the case that ϕ is less than about 1 eV for an oxide formed chemically on a metal. Another type of modification of the barrier is due to the surface states of Bardeen.[12] These surface levels are provided by adsorbed oxygen. It is known that oxygen adsorbed on oxides produces surface states about 3 eV below the level of the conduction band. These oxygen levels are empty when neutral; a negative surface charge is set up when they are filled. It is clear then that in an excess semi-conductor they will lead to the setting up of a Schottky-type barrier at a free surface. Two cases arise:

(1) The oxygen level is above the full band as in oxides (TiO_2, ZnO) that are excess conductors.

(2) The oxygen levels are below the full band as in germanium.

A metal brought into contact with a semi-conductor will normally be covered with its own oxide layer, on the surface of which there will be adsorbed oxygen. Fig. 4 shows the relevant energy levels before the metal is brought into contact with the semi-conductor. The only case in which the presence of the metal—with its oxide levels—can change the height of the Schottky barrier in the semi-conductor is when the oxygen adsorbed to metal has levels below those of the oxygen adsorbed to the semi-conductor and when the layers are brought very close together, so that oxygen on the metal draws all electrons from those on the semi-conductor. The height and width of the Schottky barrier will

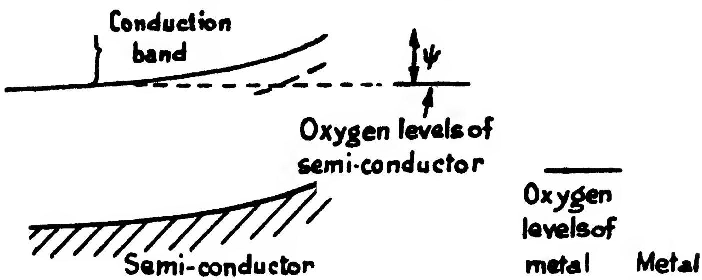


Fig. 4.

then increase and the value of ϕ for contact will depend on the work-function (with its oxide layer) of the metal used. If, however, the metal electrode is fused, the free oxygen atoms responsible for these states will not remain; they will be reduced by the metal or semi-conductor.

The properties of the contact between a metal and a semi-conductor

When a metal is in contact with a semi-conductor, as for example, a metal in contact with blue-black titanium oxide (an excess semi-conductor), electrons can be excited thermally from the impurity levels in the titanium oxide into the conduction band, from which they fall into the metal. This leaves the semi-conductor positively charged. As the process continues this positive space charge increases until no more electrons can pass into the metal. The energy level diagrams at the beginning of the process and for the final equilibrium are given in Fig. 5. These equilibrium diagrams are basic for considerations of rectification by semi-conductors.

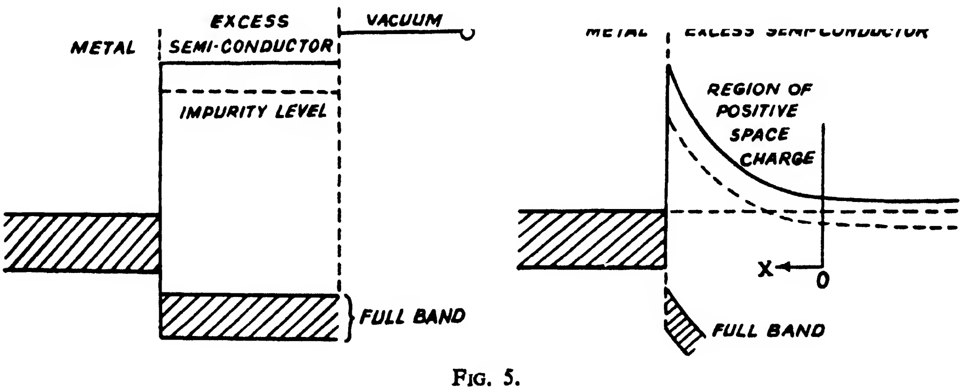


Fig. 5.

The thickness of the space charge layer can be calculated. Assuming that the semi-conductor contains N impurity centres/cm.^{3}, and that all centres in the thickness of the space layer lose their electrons, the space charge density is Ne per cm.^{3} The result is given by solving the equation

$$\frac{d^2V}{dX^2} = \frac{4\pi\rho e}{K} = \frac{4\pi Ne^2}{K}$$

where ρ is the space charge density $= Ne$,

K, the dielectric constant,

e, the electronic charge,

and V, the potential energy at a distance X from the boundary.

The solution is

$$V = \frac{2\pi Ne^2}{K} X^2 + C_2.$$

The constant C_2 becomes zero if X is measured from the edge of the space charge layer remote from the metal, *i.e.*, from the point where the impurity level in the semi-conductor begins to rise due to space charge.

Then $$X = \sqrt{\frac{KV}{2\pi Ne^2}}$$

and the width of the space charge layer is obtained by putting $V = \phi - \chi$, so that

$$X = \sqrt{\frac{K(\phi-\chi)}{2\pi Ne^2}}$$

where $\phi-\chi$ is of the order of 1 eV;
N lies between 10^{16} and 10^{19}/cm.[8]

Then, in general, $X = 10^{-5}$ to 10^{-6} cm.

In an extreme case, $\phi-\chi = 1$ eV and $N = 10^{19}/\text{cm}^3$., $X = 3{\cdot}3\times10^{-7}$cm.

The space charge layer is thus about 20 atomic layers thick.

The rectifying properties of the metal semi-conductor contact depend upon the properties of this layer. The system can be regarded as a condenser of capacity

$$C = \frac{K}{4\pi X}$$

whence, with the value of X already found,

$$\frac{1}{C^2} = \frac{16\pi^2}{K^2}\cdot\frac{K(\phi-\chi)}{2\pi Ne^2}.$$

$$i.e., \frac{1}{C^2} = \frac{8\pi}{K}\frac{1}{Ne^2}(\phi-\chi).$$

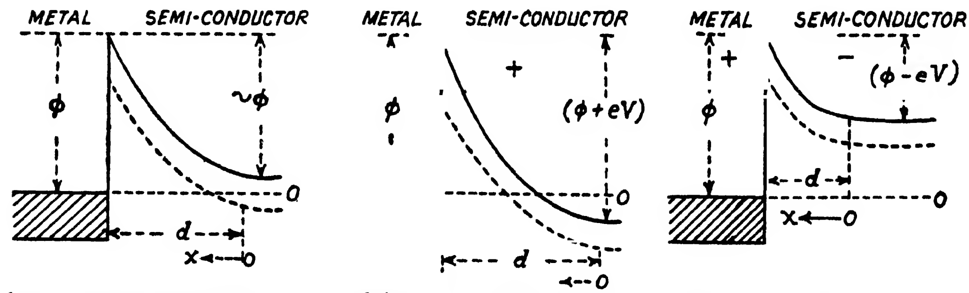
showing that the capacity depends on $(\phi-\chi)$.

Now, when a potential difference is applied across the contact, we have the following three cases shown diagrammatically in Fig. 6:—

(*a*) The energy levels for equilibrium in the absence of any potential difference.

(*b*) The energy levels when a potential difference, V, is applied in the direction shown.

(*c*) The energy levels for a potential difference of opposite sign.



(a) NO APPLIED FIELD. (b) FIELD APPLIED IN REVERSE DIRECTION. (c) FIELD APPLIED IN FORWARD DIRECTION.

FIG. 6. Electron energy diagram showing rectification at a metal-semiconductor contact.

The reference level for the measurement of V in these diagrams is the upper occupied level for the electrons in the metal at the absolute zero of temperature.

In (*b*) the thickness of the space charge layer increases and in (*c*) it decreases with the applied potential. Corresponding values of the capacity are given by

$$(b)\quad \frac{1}{C^2}=\frac{8\pi}{K}\frac{1}{Ne^2}(\phi-\chi+V)$$

$$(c)\quad \frac{1}{C^2}=\frac{8\pi}{K}\frac{1}{Ne^2}(\phi-\chi-V)$$

If V and C are measured, and $1/C^2$ is plotted against V, then $(\phi-\chi)$ can be calculated from the value of $1/C^2$ for $V=0$, and N is obtained from the slope of the curve.

It is found experimentally that the current which can be driven across a metal semiconductor contact for a given E.M.F. depends on the direction of this applied E.M.F. There is a direction of easy flow and a blocking direction. For the case so far discussed, namely a metal in contact with an excess semi-conductor, the direction for easy flow of electrons is from the semi-conductor to the metal. This result can be derived theoretically but would depend on the theoretical approach.

Wilson, Nordheim, Frenkel and Joffe assumed that electrons could travel by 'tunnel effect' through the potential barrier between the metal and the semi-conductor. If this were the mechanism, the direction of easy flow of electrons would be from the metal to the semi-conductor as in Fig. 6(*b*), because of the high electron concentration in the metal. This result is, however, contrary to the observed direction of rectification.

Mott,[12] on the other hand, assumed that the electrons must pass over the potential barrier by a thermionic emission mechanism. In equilibrium, equal numbers of electrons will cross the barrier in both directions in a given time. For an electron to pass from the metal to the semi-conductor it must acquire an energy, $\phi-\chi$. For electrons to pass in the opposite direction they must gain an energy increment determined by the sign of the applied potential. Referring again to Fig. 6(*c*), a resultant flow of electrons takes place from the semi-conductor to metal when the semi-conductor is negative with respect to the metal. When the potential is applied in the opposite direction, a resultant flow of electrons will take place from metal to semi-conductor, but this current is not as large as in the previous case because of the smaller exponential factor. Thus the direction of easy flow of electrons is from semi-conductor to metal, when the semi-conductor is made negative with respect to the metal.

The current flowing across the contact is given by

$$i = evN_0Fe^{-(\phi-\chi)/KT}(1-e^{eV/KT})$$

where e is the electronic charge,

v is the mobility of the electrons in the system,

N_0 is the number of impurity centres/cm.^{3}, and

F is the field.

Commercial rectifiers, however, use 'deficit' or *p*-type semi-conductors such as cuprous oxide and selenium. The theory of the direction of easy flow of electrons is similar to that for the case of excess semi-conductors. In this case, Fig. 7 shows the energy levels under the initial conditions and when equilibrium has been reached. Electrons in the metal are captured by the impurity centres in the insulator, and build up a negative space charge, leaving the metal positively charged. This is the reverse of the state of affairs for a metal in contact with an 'excess' or *n*-type semi-conductor. The

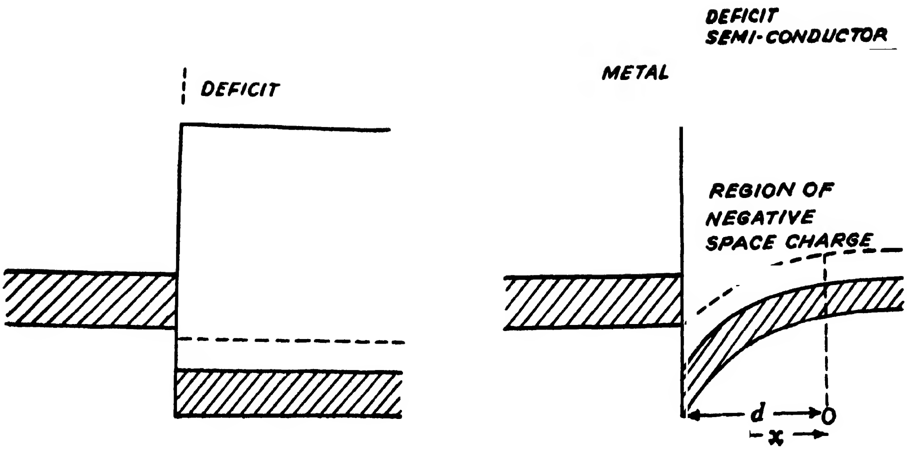
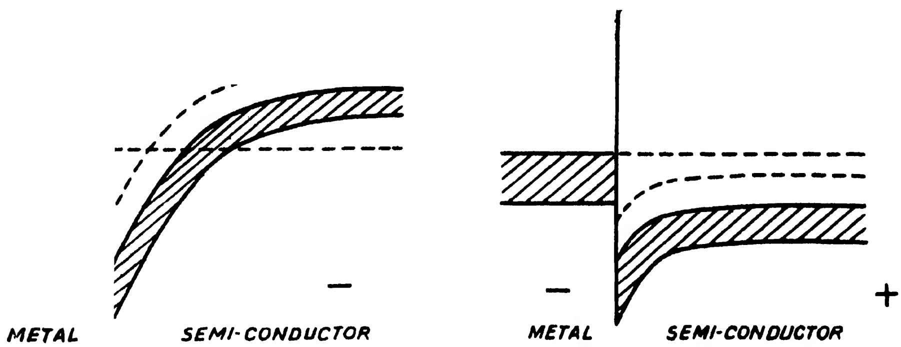


Fig. 7.

direction of easy rectification is now that for which the metal is negatively charged with respect to the semi-conductor. There is then an easy direction for the flow of positive holes from the semi-conductor to the metal which is equivalent to an easy flow of electrons from metal to semi-conductor. The corresponding energy levels are shown in Fig. 8.



Field applied in reverse direction

Field applied in forward direction

Fig. 8.

The characteristic curve of current against potential is given in Fig. 9. It may be seen that in the blocking direction, when the field in the barrier is sufficiently strong, the resistance decreases with increasing voltage, instead of tending to constant value as predicted by the theory.

According to Mott, this decrease in resistance can take place through two mechanisms:

(*i*) The so-called Schottky effect, *i.e.*, lowering of the work function in strong fields which occurs owing to the image force between an electron and a metal.

(*ii*) Strong field emission.

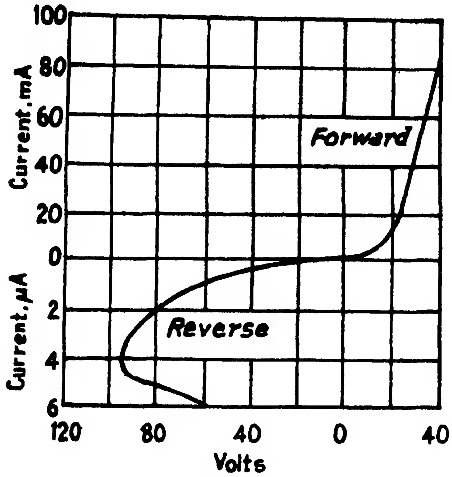


Fig. 9.

In all rectifiers, at sufficiently strong back-voltage, the current increases rapidly. This may be due to either of the effects (*i*) and (*ii*) listed above. A proper analysis of the experimental behaviour in terms of the theory has not been attempted so far. Nevertheless, we find that this phenomenon plays a vital rôle in the proper explanation of the action of different types of coherers discovered by J. C. Bose.

Action of coherers

If two metal electrodes (same material) coated with metallic oxides (*n*-type semiconductors) and adsorbed oxygen layers are brought near each other, the simplified energy level diagram is represented by Fig. 10(*a*). Fig. 10(*b*) represents the situation when they are brought closer to each other with a consequent rise of Schottky barrier on both sides facing the electrodes. The existence of Schottky barriers on either side will obviously affect the resistance at the contact between two specimens of the same semi-conductor, giving a high resistance varying as $e^{-\frac{\phi}{KT}}$ with temperature. If a bias voltage greater than KT/e ($\sim$0·025 volt) is placed across such a contact, the resistance should vary with the current in a non-linear way. It is not, however, clear whether the contact should behave in both directions like a rectifier in the forward or in the blocking direction. Actually silicon carbide, whether 'excess' or 'deficit', behaves in the former manner, and high back-voltage germanium rectifiers in the latter. According to Fig. 10(*c*), one barrier hill happens to be in the blocking direction, while the other is in the forward direction Since the same current flows through the entire circuit, the barrier in the blocking direction should play the more important rôle in limiting the current flow.

Now, the incident electromagnetic wave from the transmitter, falling on the receiver assembly, will induce a unidirectional voltage across the non-ohmic contact resistance, The magnitude of the induced voltage may be of the order of a few volts only. Nevertheless, on account of the extreme thinness of the barrier layer ($\sim 10^{-6}$ cm.), the electric field developed will be of the order of $\sim 10^{6}$ volts/cm. This would lead to field emission, as suggested by Mott in connection with the breakdown mechanism of metal rectifiers. These energized electrons would be lifted into the conduction band, leaving holes in the full band. The positive holes will be attracted to the barrier region, and if enough of them are trapped there, the summit of the potential hill would be pulled down as in Fig. 10(*d*). Thus we now have a relatively free flow of electrons from one electrode to the other.

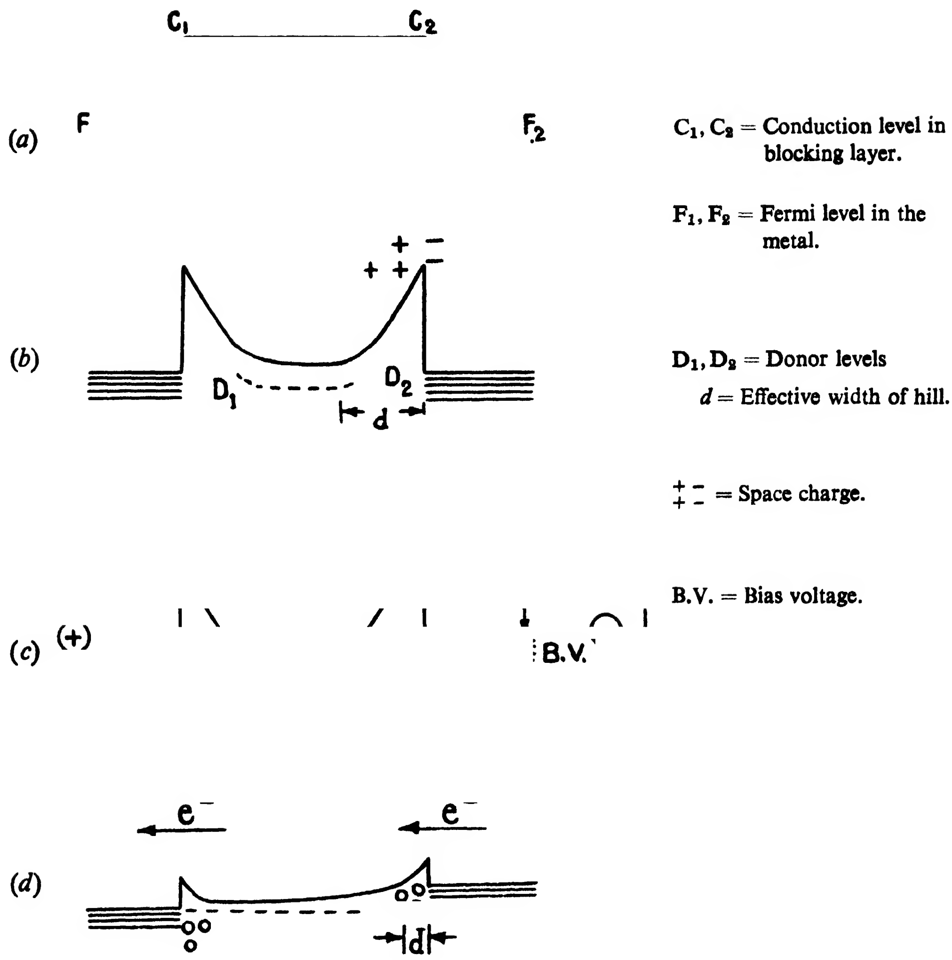


FIG. 10.

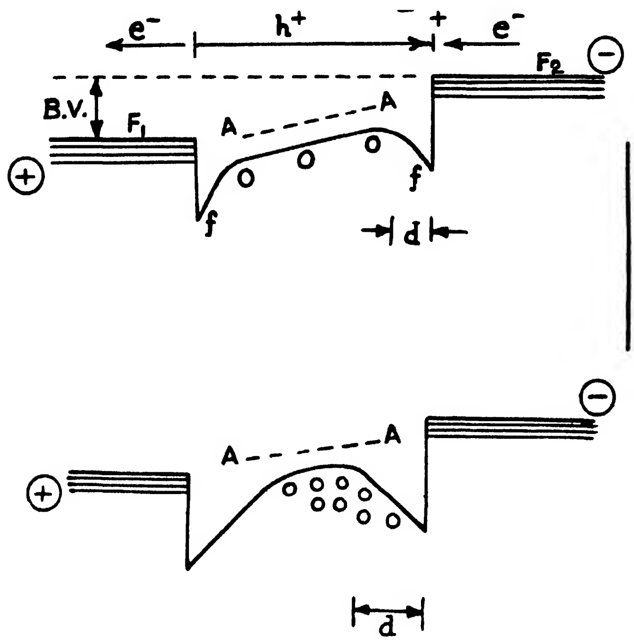
This action will continue until the abnormal concentration of positive holes disappears through recombination with the electrons. The entire action is like that of a dam which normally prevents the flow of water. The positive holes act to lower the height of the dam temporarily, thus allowing a rather large quantity of water to pass. The response is thus relatively slow since the flow lasts as long as the life-time of the abnormal hole concentration in the barrier.

Incidentally, there may be another simultaneous effect. As the summit of the potential hill becomes lower, the width of the barrier decreases, resulting in a 'quantum-mechanical tunnel effect'. The effect of a mechanical disturbance like tapping for the restoration of initial condition now becomes clear. Its purpose is two-fold in character: (1) removal of the trapped holes from the barrier region, and (2) stopping the tunnel-effect by increasing the barrier width.

Mild heating of the junction produces the same result.

If the contact be energized frequently, the concentration of holes in the *n*-type semiconductor (corresponding to Bose's positive coherer) will increase and give rise to the phenomenon of fatigue. It is also clear why the fatigued coherer will show, in general, greater conductivity than in the initial condition.

The explanation of the increase in resistance of Bose's negative coherers follows immediately. It may be remembered that we have now to deal with metallic oxides which form *p*-type semi-conductors. The relevant energy-level diagrams in Fig. 11 will



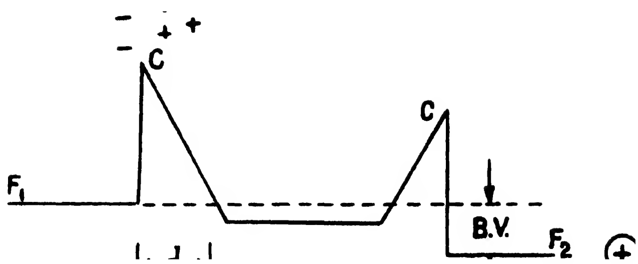
AA = Acceptor level.
ff = Full band.
(both in blocking layer).

FIG. 11.

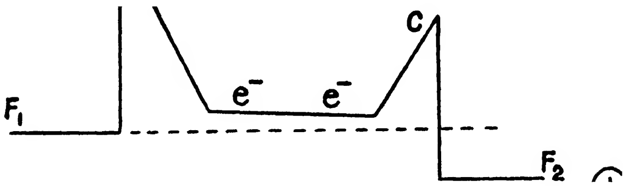
show that the accumulation of holes, created by the field emission, will now increase the height of the Schottky barrier, resulting in a diminution of the basic current. In this case, we do not expect any tunnel effect to function and the receivers should be of the self-recovering type. Nevertheless, tapping is sometimes resorted to for quick dispersal of trapped holes in the surface states. Frequent energizing of the negative coherers also results in a fatigue, the resistance of the fatigued specimen being greater than that of a fresh one. Thus, we find that in either case, the fatigue is due to an abnormal concentration of positive holes in the full band, which gradually disappears with the passage of time.

PHENOMENON OF REVERSAL

When the incident radiation is comparatively weak, the voltage induced across the contact is quite inadequate to trigger the field emission. Nevertheless, it excites the Fermi level of the semi-conductor. For a *n*-type semi-conductor in contact with a metal, more electrons will flow into the metal under equilibrium condition, thus raising the height of the barrier layer. Consequently, the current in a positive coherer will diminish under the influence of a sub-minimal intensity of stimulus. This is shown in Fig. 12. On the other hand, in the case of a *p*-type semi-conductor, the rise in Fermi level of the semi-conductor will diminish the heights of the Schottky barrier between the metal and semi-conductor. Consequently, the current will increase in the case of a negative coherer under a sub-minimal excitation. In either case, there will be a definite tendency towards self-recovery and no tapping should be necessary.



Barrier admits weak infiltration



Barrier increased.
FIG. 12.

The phenomenon of reversal observed in certain coherers, under the influence of sustained excitation, may be due to the readjustment of impurity centres. It appears that some *n*-type semi-conductors have a tendency to become *p*-type and *vice versa*, under continuous stimulation, which obviously causes migration of interstitial atoms. Sufficient data on this point are lacking. Nevertheless, it is known that due to the interaction of impurity centres, one can observe a continuous transition from the behaviour of a semi-conductor to that of a metal.

Quantitative measurements in support of these hypotheses will be published elsewhere.

ACKNOWLEDGMENT

In conclusion we wish to pay our homage to the sacred memory of late Lady Abala Bose, at whose instance the present investigation was undertaken.

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XVIII. A REPORT ON THE STUDY OF THERMOLUMINESCENCE

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(*Received for publication on February 9, 1955*)

When some solids are irradiated with ionizing radiations like X-ray or cathode rays, they often exhibit fluorescence followed by a long period phosphorescent afterglow. Again, if the irradiated sample is heated, the stored energy is released in the form of radiation, emitted at various temperatures characteristic of the sample. This thermo-stimulated release of energy is commonly known as thermoluminescence. The capacity of substances to store energy is large at low temperatures, so thermoluminescence is pronounced if the irradiation is carried out at low temperature (*e.g.*, at $-184°C$). We may plot in a thermoluminescence curve the total intensity obtained from the sample at various temperatures during heating. From the curve, the trap depths of light-storing states below the conduction band, can be evaluated [1]. Shallow traps yield glow peaks at comparatively low temperatures, while deeper traps are released at higher temperatures. Quartz, alkali halides, calcite, glasses and many other substances show this kind of thermoluminescence. Of late, thermoluminescence has been a useful tool in many problems of research. Dosimetry of radiations, study of heterogeneous catalysts, ionic nature of elements in glasses, and identification of clay minerals are some of the uses to which thermoluminescence has been put.

Study of thermoluminescence of alkali halides was initiated in this laboratory in 1950, as a part of a larger programme of investigating solid state and of co-ordinating fluorescence study with the results of soft X-ray spectroscopy. The fluorescence spectra of alkali halides both at room and low temperatures had already been studied [2, 3, 4]. Measurements of the afterglow [5] decay rates had also been done, so thermoluminescence study of alkali halides and also of some organic substance was undertaken, with a view to clarify the processes involved during energy storage in these phosphors.

In this laboratory, thermoluminescence has been studied by exciting the sample at liquid oxygen temperature, in a demountable cathode-ray tube fitted with a window of quartz. The sample is mounted as a fine coating on a hollow bulb made of thin silver. The bulb can be filled with liquid oxygen to keep the sample at low temperature and it may be rapidly heated with an electric heater immersed in the bath. A thermocouple on the surface of the bulb, connected to a Moll galvanometer, gives temperature of the sample. Another galvanometer connected to the photomultplier tube, placed facing the specimen, gives luminescence intensity. The movements of the two galvanometers during thermoluminescence are recorded on a slow rotating photographic drum. A typical example of thermoluminescence curve is shown in Fig. 1.

For recording thermoluminescence, different photomultiplier tubes (931A, 1P28, 1P22) have been employed to suit the emissions of the different samples. Fluorescence spectra of the substance being known from a previous study, there was no difficulty in selecting the photomultipliers. Although low rate of heating (0·25°C/sec.) is usually preferred, yet it has been observed that, in the case of many phosphors, the weaker peaks get flattened out unless the rate of heating is high (6–10°C/sec.). A high rate of heating

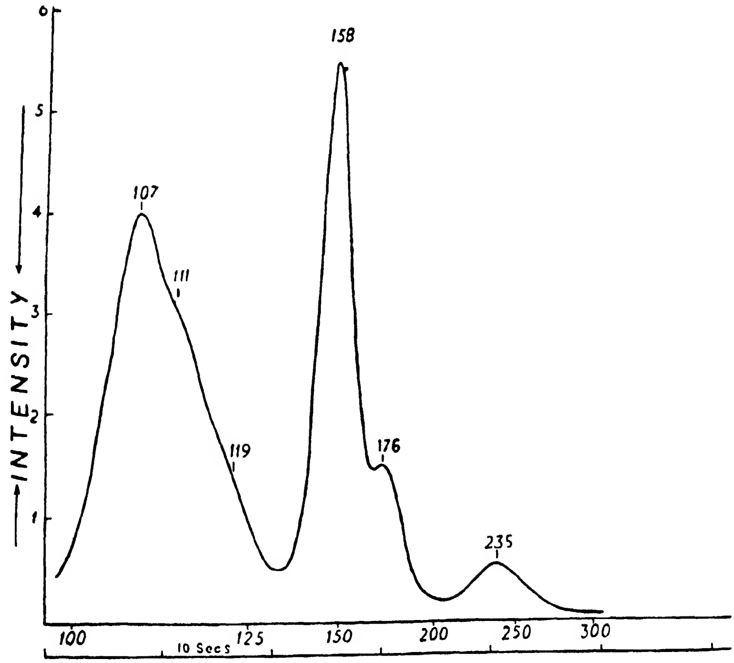

FIG. 1. Thermoluminescence of KI.

was often maintained and a fine film of powdered sample was found more suitable than a single crystal. For recording the spectral nature of the different glow peaks, two photomultipliers, sensitive in different regions, were made to record thermoluminescence simultaneously during the same run of the experiment, and optical filters were used to separate out the emissions.

Quite a number of alkali halides, both pure and activated, has been studied and some of the results have been published[6,7]. These halides yield a number of thermoluminescence peaks between 90°K and 600°K. It has been possible to explain some of the results of afterglow decay rates in the light of information obtained from thermoluminescence study. The effects of thallium activation of samples on thermoluminescence have been investigated and it has been found that in some samples thallium produces a new peak of its own, without affecting the peaks of the parent lattice. But in some samples, like KCl and KI, it completely changes the thermoluminescence curve. From the comparative method of study with optical filters, it has been found that the different peaks emitted by a specimen are not spectrally identical. In general the peaks emitted at high temperatures are rich in emissions of ultra-violet and blue regions. But thorough study of any peak with an ordinary spectrograph is not possible, because the individual peaks disappear within a few seconds. To study the spectral nature of individual peaks, construction of a rapid spectrophotometer was deemed necessary and has been recently completed. With the help of this spectrophotometer some interesting results have been recently obtained (see Figs. 2, 3, 4 and 5).

The automatic rapid scanning spectrophotometer employs two concave mirrors of 25 cm. focal length and large focal ratios of $f/4{\cdot}2$ constructed from stainless steel and a large prism of quartz. Light from the first slit is collimated by the first concave mirror, and, after dispersion by the prism, the beam is focussed by means of the other concave

mirror. But before falling on the exit slit, the spectrum is reflected by another plane mirror. The latter is mounted on a turntable, which can be made to oscillate to and fro with the help of an induction motor and a cam. The entire spectrum (ultra-violet and visible) sweeps before the slit in about 0·95 second and flies back instantaneously to the original position by a cam arrangement. Just behind the exit slit is placed the photo-multiplier tube which receives the light. The output of the photomultiplier tube passing through a pre-amplifier is amplified and displayed on a Dumont 304H cathode-ray tube with long time. A micro-switch attached to the cam triggers the sweep circuit every time the ultra-violet end of the spectrum just comes near the slit so that the same part of the spectrum is given at the same position. During each sweep, a specially adopted synchronous 35 mm. camera arrangement photographs the intensity distribution curve displayed on the cathode-ray screen. With the help of this spectrophotometer, the spectral intensity distribution of the emission can be photographed in less than one second and the apparatus is capable of giving all the necessary information during the entire thermoluminescence experiment. Not only the spectral composition and the intensity of the different peaks can be obtained, but also the changes in emissions in subsequent periods of a single thermoluminescence can be easily and accurately studied. Commercial types of photomultipliers were found to be not sensitive enough for this work, so a special photomultiplier with 19 dynodes was procured from France.

It is well-known that most of the solids (like alkali halides, quartz, calcite), on irradiation with ionizing radiations, develop colour centres. From simultaneous changes in colour centres and by recording diffuse reflectivity during thermoluminescence, it has been shown that some of the luminescence peaks correspond with thermally actuated transformation in colour centres. It has been found that thermoluminescence-behaviour of alklali halides is very susceptible to previous history of heat treatment of the sample. Other properties have also been studied in this laboratory.

Thermoluminescence of some aromatic hydrocarbons both solids and liquids between 90°K and 250°K has also been investigated. This work gives information regarding the metastable states of the molecules excited by cathode-rays at low temperatures. The depth of the metastable states below the upper excited states, as measured from the thermoluminescence, agrees fairly with that obtained from the study of fluorescence and phosphorescence spectra. Thermoluminescence opens a new method of investigation of the metastable states of the molecules.

This article would not be complete unless another interesting application of thermoluminescence is mentioned. We know that many naturally occurring minerals exhibit thermoluminescence. Recently a number of samples of sands procured from various parts of this country was studied. All sands show feeble thermoluminescence, but those from Bargarh and Mangalhat showed pronounced one. Measurement of γ-ray counts in the case of the latter showed slightly extra counts over the background. This leads to the possibility that thermoluminescence might be developed as a preliminary method of detecting radioactive minerals. Many minerals (like bentonite) are often found to yield thermoluminescent radiation. The ultimate reason for the occurrence of thermoluminescence in natural minerals has not yet been found. Radioactivity may play some part in this occurrence, but it is yet too early to make any definite statement on this matter.

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FIG. 2. Shows the fluorescent spectra of anthracene.

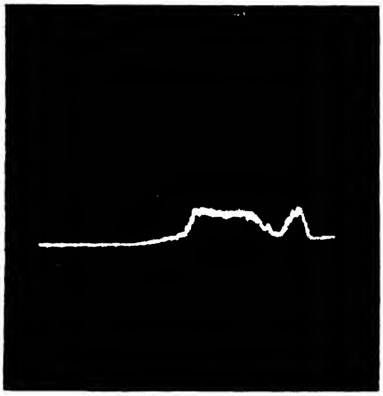

FIG. 3.

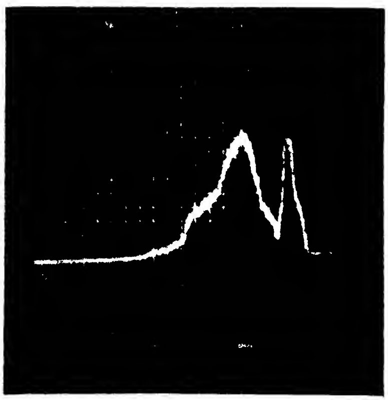

FIG. 4.

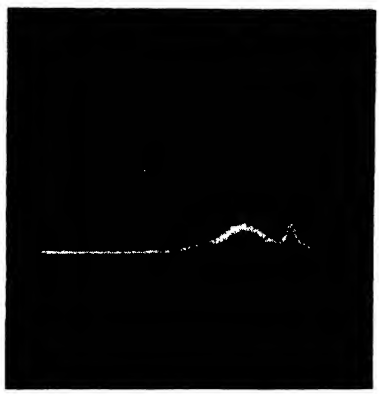

FIG. 5.

FIGS. 3, 4 and 5 give the radiation as observed from a sample of irradiated NaCl during heating. (Note change of character with time.) Figs. 3, 4 and 5 are photographs taken at 3, 7 and 17 secs. respectively after the commencement of heating.

XIX. MODERN TAXONOMY AND CYTOGENETICS

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(*Received for publication on February 18, 1955*)

Introduction

The aim of taxonomists is to evolve a system of classification which brings out the phylogeny or true affinity between the various groups of plants. In practice this aim is, however, only achieved by evaluating resemblance and difference in the largest possible number of characters, phylogeny being deduced subsequently. Although some of the recent systems of classification may be interpreted on a phylogenetic basis, it would appear that many of the deductions are arbitrary and often controversial. Thus, in lower taxonomic categories, such as species and sub-species the effect of parallel mutation may make our phylogenetic interpretation almost an impossible task. Similarly in higher categories, parallel or convergent evolution may considerably obscure phylogeny. Huxley [1] has rightly pointed out that taxonomy can represent phylogeny adequately only when differentiation is divergent. Whenever it is 'reticulate', whether by allotetraploidy or by hybridization followed by apogamy, the existing taxonomic methods inevitably fail to indicate phylogeny.

Taxonomic categories.—Taxonomy was hitherto mainly based on the study of morphological and physiological characters as well as geographical distribution of plants. During the last 25 or 30 years taxonomic investigations were also made on cytological basis. The basis of modern taxonomy should be a proper understanding of the concept of species and the various smaller groups within the species such as *sub-species*, *varieties* and *forms*. Biologically strongly isolated natural groups of the lowest rank are generally classified as distinct species, the higher ranks of isolated groups being genera, families, etc. The above-mentioned unit-subgroups within the species, although morphologically, geographically or ecologically more or less clearly separable, are always taken to be interfertile. Love [2] has proposed to classify the major geographical races as *sub-species*, the minor geographical races or local *facies* as *varieties* and the morphologically recognizable types within these subgroups and without any definite geographical area but appearing sporadically as *forms*. Ecological variants which may or may not be morphologically distinct are classified as *ecotypes*.

Cytogenetics and Species Status.—It is well known that no criterion could be found which alone can define a species. The classical method of morphological analysis based on resemblances and differences gives a fairly good range of characters by which a species can be identified only when the limits of the species are well marked. But in many instances it has been found that two species which resemble each other very closely and are often indistinguishable, appear to be cytologically and genetically distinct on critical analysis. *Argimonia eupatoria* L. and *A. odorata* (Gonan) Mill., for instance, are morphologically very much allied, being differentiated by fruit and indumentum characters, but are quite distinct cytologically with $2n = 28$ and 56 chromosomes respectively (Brittan).[3] The example of *Drosophila simulans* and *D. pseudoobscura* may also be cited. Keck [4] has shown that in case of *Achillea millefolium* complex, where it is

difficult to separate members morphologically, their physiological and cytological differences are, however, quite distinct ($2x = 36$ or 54). These members occur as climatic races or *ecotypes* within two genetically distinct species which are separated by a difference in chromosome number. Similarly in *Solanum nigrum* while the tetraploid form ($2x = 48$) can readily be distinguished from the diploid ($2x = 24$) and the hexaploid ($2x = 72$), the morphological differences between the diploid and hexaploid forms are indeed very small (Bhaduri).[5, 6, 7] These three forms are also not readily intercrossable. The hexaploid form with dull purplish black berries as against the shiny black and orange berries of the diploids and tetraploids respectively must have arisen by a process of amphiploidy out of the diploid and the tetraploid forms. Such *intraspecific* chromosome races are not easily classifiable as sub-species or varieties and have to be raised on cytological and genetical evidence to specific status. This argument holds good in case of all amphiploid plants which are either raised experimentally or are found in Nature.

There is a general tendency among cytologists and taxonomists to accept those forms which differ from each other in their chromosome number but are not clearly distinguishable morphologically, as true chromosome races. It is interesting to note, however, that many of these real intraspecific chromosome races have previously been described by classical taxonomists as separate species but later considered synonymous. It is also known that although 'intraspecific chromosome races' have been reported within about 10 per cent of the species of Northwestern Europe almost all these races have previously been described as separate species by classical taxonomists.

The following examples have been quoted by Love.[2]

> *Phleum pratense; P. nodosum; P. alpinum; P. commutatum; Dactylis glomerata; D. aschersoniana; Acetosella vulgaris; A. tenuifolia; Saxifraga stellaris; S. foliolosa; S. nivalis; S. nigra; Veronica longifolia; V. maritima; Artemisia borealis; A. bottnica*, etc.

Love[2a] has quite rightly suggested that if difference in chromosome number is observed among morphologically less distinct types, previously described as species but not generally accepted, they should always be taken as a clear evidence of the correctness of regarding them as separate species.

Sometimes, as in the section *Tuberarium* of the genus *Solanum* in which numerous species have been described based on minor morphological differences, detailed cytogenetic studies have shown that many of the species with the same chromosome number may only be varieties or sub-species of the same species (Swaminathan and Howard).[8] Thus, cytogenetic data help to clear complex situations created by both the 'lumpers' and 'splitters' among the taxonomists.

It is now generally recognized that an understanding of the process of species formation and their geographical distribution is very necessary in modern taxonomy. Cytotaxonomical methods have proved to be of immense help in this field of investigation. In a number of cases it has become possible to repeat speciation artificially by doubling of the genome or by the addition of genomes of different species, *e.g. Nicotiana tabaccum* from *N. silvestris* and *N. tomentosiformis*; *Brassica juncea* from *B. nigra* and *B. campestris*; *Galeopsis tetrahit* from *G. pubescens* and *G. speciosa*; *Rubus loganobaccum* (hexaploid) from *R. ursinus* (octoploid) and *R. idaeus* (autotetraploid form of European raspberry).

Species origin and differentiation.—Turesson has suggested a biosystematic classification of groups or units distinguished on ecological and geographical variations, *e.g. caenospecies, ecospecies* and ecotypes. A new approach has been attempted by Clausen,

Keck and Hiesey [9] for a cytological and genetical understanding of the various groups suggested by Turesson. They consider *caenospecies* as equivalent to a genus, *ecospecies* as species and *ecotypes* as subspecific segregates. According to Keck, inherent relationships in plants can be studied by experimental methods and upon a knowledge of them a natural classification can be based. The outstanding result which can be obtained from this modern approach to taxonomy is well illustrated in case of *Gossypium* species. Before the application of cytotaxonomical methods, *G. thurberi* and *G. aridum* were thought to belong to other genera, the former having been referred to as *Thurberia thespesioides* A. Gray and the latter as *Erioxylum aridum* Rose et Standl. It is now clear that these two species are not only congeneric with *Gossypium* but belong to the same caenospecies as the American diploids, *G. raymondii*, *G. harknessii* and *G. armourianum*. Similarly, the outstanding results obtained in the proper understanding of species relationship and lines of evolution in *Crepis*, *Triticum* and *Datura* by the application of cytogenetical methods is well known. In the genus *Oenothera* also the interrelationship between species and the lines of evolution have become much more clear since the application of 'Renner's Complex theory' and the principle of nonhomologous interchange of chromosomes. Here, however, parallel and reverse mutations have made establishment of affinities very complicated.

Another line of cytogenetical investigation which has thrown much light in tracing affinities of species is the study of the chromosome-nucleolus relationship. This includes a study of the maximum number of nucleoli corresponding to maximum number of secondary constrictions of chromosomes and the relative size difference and homology of nucleoli in addition to the karyotype analysis of species (Gates,[10] Bhaduri and Bose [11]). In *Oenothera* for instance, while the homozygous species have homomorphic pairs of nucleoli, the heterozygous species have heteromorphic pairs of nucleoli (Bhaduri).[12] From a study of the chromosome-nucleolus relationship in *Triticum* and *Aegilops* species Pathak [13] was able to suggest the origin of cultivated wheats with *A. squarrosa* as a probable parent. Similarly, Sikka [14] from cytological considerations suggested the amphidiploid origin of *Brassica juncea* from *B. nigra* and *B. campestris* which was later confirmed by Ramanujam and Srinivasachar [15] by experimental synthesis of *B. juncea*.

Cytogenetical investigations, therefore, not only help to indicate differences between species but also provide an insight into the way in which these differences came about. Lamprecht [16] in a study of interspecific crosses between *Phaseolus vulgaris* × *P. coccineus* has shown that a single gene can cause an insurmountable barrier between two species. When one allele of such an interspecific gene is transmitted artificially to another species it causes sterility and creates species barrier.

Conclusion

From the above brief survey of the application of cytogenetical knowledge to a proper understanding of the relationships of closely allied groups of plants it would be sufficiently clear that greater collaboration among cytologist, taxonomist, plant geographer and plant breeder is necessary. In the past, taxonomical work was mainly done in India purely on morphological considerations and the pioneer work done on this line was indeed excellent. With the modern methods of cytology and genetics it is now possible to get a critical and clear idea of a particular species in relation to its allies. These methods should be employed in collaboration with a herbarium taxonomist and the status of a particular species or variety be decided based on different lines of evidence. There is indeed unlimited scope of work on these lines in India.

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XX. MOLECULAR STRUCTURE AND THE UNDERSTANDING OF VITAL PROCESSES

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Since its foundation, the Bose Institute, inspired by the work of its founder Sir Jagadis Chandra Bose, has been distinguished for its skilful combinations of researches of physical and biological interest. It has pioneered the new subject of biophysics, on the one hand, in studying minute physical responses of living organisms; on the other by the study of effect of radiations and other physical stimuli on them. But though these remain the main field of biophysical research there is still another one, the relation of structure to function, a study which is now being pushed down to the ultimate region of atomic dimensions.

This short essay is an attempt to indicate the implication in biology of the new knowledge that is being won, by physical methods, in the structure and behaviour of large molecules. Biophysics itself has come to prominence in recent years largely due to the impact of new physical tools of research on old fields of biological studies. Radioactive tracers, autoradiography, the electron microscope, the electroencephalograph and electronic computors, are all playing an increasing, and sometimes a decisive, rôle in biological research. There is a danger in this that the method should take too large a precedence over the object—the deeper understanding of the biological processes and origins.

Up to a point the new methods only render more precise the knowledge won by older methods. The electron microscope has, for the most part, revealed through its higher resolving power what had been guessed by the most acute optical microscopists. It touches, however, and at some points just oversteps, the region where the appearances and behaviour of bodies cease to be that which we are accustomed to on our scale of handling things. The ultimate membranes, fibres and particles, that serve to describe the micro-anatomy of the cell, reach further into the region of colloids where chemical begin to match mechanical forces.

It is this region, with dimensions ranging from 1 μ to 1 mμ or from five thousand to five atomic diameters, that still remains the least understood in the spectrum of dimensions. The fact that the smallest living things, either independent beings such as viruses, or integral parts of larger units such as chromosomes or mitochondria, are of these dimensions shows that knowledge gained here is likely to be of fundamental biological importance. Here also the link has to be made between chemical knowledge dealing with individual atoms and the more complex interactions of biochemistry.

We are now just beginning to learn something of this region by a kind of combined operation reaching from electron microscopy to chemistry and including the diffraction techniques of X-rays, electrons and neutrons, to bridge the regions between them. What this has revealed, though still somewhat tentative, promises to lead to a picture of structures and processes that should make the transition from chemistry to biology understandable.

This is, as yet, not so much in complete analysis of actual structures of biological entities, such as chromosomes and viruses—these still remain too complex—but rather

in the unravelling of some of the patterns and laws of formation of simpler intermediate formations, especially polymers and fibres.

As we move away from the atomic scale to larger and larger structures, the importance of shape and size makes itself felt, as also do the effects of forces intrinsically weaker by successive degrees than those primary valence forces that bind together the carbon, nitrogen, oxygen and hydrogen atoms that form the main constituents of organic structure. Of these, far the most important is the hydrogen bond of strength from 4 to 8 K cal/mol less than a tenth of a primary valence bond according to the degree of acidity, and far weaker still are the Van der Waal's forces of only some 0·4 K cal/mol. Beyond these in turn are the still vaguely defined long-range forces which exist between the molecules of colloidal dimensions responsible for the aggregations of gels, tactoids and coacervates, of which more later.

The function of the weaker short-range forces in systems such as occur in biology, that is in aqueous solutions containing a moderate concentration of free ions, is two-fold. In the first place they serve to bind small molecules together to form aggregates. These are usually of a temporary nature as they are broken up by the heat motion of the medium, but the unions are nevertheless important as an initial step to further bond formation and hence to polymer synthesis. In the second place it is these forces, acting between parts of the same molecules, especially of chain-polymer molecules, that are responsible for the folding or coiling of these molecules to form cylindrical or spheroidal structures and thus profoundly modifying their physico-chemical behaviour. According to their strength they determine whether a polymer can remain in a flexible, rubber-like state, is rigid and elongated as in desoxyribonucleic acid or in viruses of the tobacco mosaic type, or are completely curled up as in globular proteins and viruses. How labile such g-f (globular-fibrous) transformations can be is shown by the acid-induced reversible formation of insulin or the potassium ion induced g-f change of actin.

The very lability of these transformations has in the past limited their understanding by chemical techniques. Practically all chemical treatments alter the state of such systems and further, the possible foldings of flexible molecules are of an altogether different order of complexity even from those that determine the already difficult stereochemistry of sugars or terpenes. On the other hand, the techniques of physical or colloid chemistry while they do not disrupt these complexes are extremely indirect and cannot be used to determine their structures.

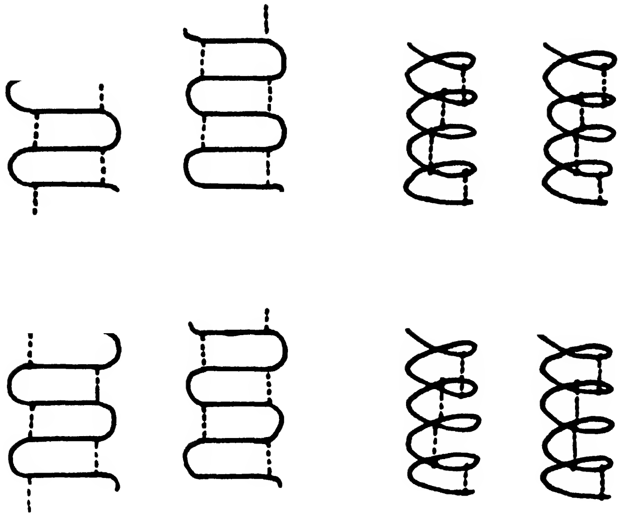
We are left with two approaches from which we may hope for some advance—the direct analysis of structure by X-rays and the building up of possible structure models on the basis of information of the geometrically and physically possible types of molecule derived from the study of simpler structures, first by X-rays and now increasingly by electrons and neutrons as well.

The conception that seems to be emerging from such studies is one which is based on an essentially linear geometry. The ultimate coherence of the large molecules which form not only the structural basis of living matter but are also responsible for the pattern of its metabolism, is assured by their forming chains of considerable but various lengths bound together by primary valence bonds. The effective units of these chains seem to be variants of a limited number of basic organic micro-molecules or residues, chiefly the amino-acids and the sugars, exemplified in proteins and polysaccharides. There are besides the seemingly all-important inorganic phosphate linking groups $\text{-O}\underset{\text{O}}{\overset{\text{O}}{\text{P}}}\text{O-}\underset{\text{O}}{\overset{\text{O}}{\text{P}}}\text{-O-}$

which appear in the nucleic acids. Joined to these, but apparently not so often themselves forming part of the long-chain systems, are the nitrogenous ring compounds—the purines, pyrimidines and pyrroles—and the fats. Two and three dimensional polymeric structures which would be produced by cross-linking linear polymers with other primary valencies seem to be rare, except for the relatively weak -S-S- intra-catenary links in proteins. Where they occur it is only in practically dead, hard structural tissues such as wood—lignin bonded cellulose—the tanned chitin of insects and the vulcanized keratin of vertebrates. This is probably because of the chemical as well as physical rigidity of two or three dimensional structures with the lack of response to small changes in the ionic environment which this would entail and would not be suitable for rapidly metabolizing molecules. A lightly cross-linked chain can uncoil and recoil itself in a different way. This disposition may, however, be more than functional. The mode of formation of biological macro-molecules would seem to involve a definite sequence of additions of micro-elements which will lead normally only to a linear aggregate.

The very nature of a linear aggregate of atoms bound by primary valencies implies flexibility, for these bonds are set at angles of 107° to 120° to each other and some degree of free rotation is possible round them. It is here that the secondary valencies (as well as weak primaries such as -S-S-) can, and must, come into play. Two general kinds of cases can arise between which there is every degree of intergrading. Where the concentration of macro-molecules is high and where there is as well some tendency to orientation, such as pressure or mechanical stress, the chains will tend to be as straight as possible, and secondary valencies will, in general, be formed between them (inter-catenary) as they are, for instance, in cellulose or silk fibroin. Where, on the other hand, there is only a small concentration and no orienting mechanical field the secondary linkages will be primarily inside each chain (intra-catenary) (Fig. 1) and a coiled or globular aggregate will be found.

Any system of linked asymmetric units with internal secondary links will tend to take a spiral form. If the units are identical the spiral will be a regular one. This ideal case is most easily realized in the artificial polypeptides where most seem to follow the pattern of the α-helix proposed by Pauling. This structure, predicted from measurements made on crystalline amino acids, was found to predict almost without modification the X-ray patterns observed for polymethyl and polybenzoyl glutimate. It was a natural extension to assume it would also account for the so-called α-keratins found in wool and horn and capable of considerable extension to the evidently inter-chain linked β-keratin of silk. For α-keratin greater modifications of the α-helix are required which might be expected from the fact that here there is a considerable variety of side-chains. The further extension of the α-helix to other proteins, especially the so-called globular proteins with no marked fibre-like properties, seems much more doubtful. Indeed, critical studies have shown that no structure made of a packing of parallel straight chains can account for the observed disposition of X-ray reflections. There is additional chemical evidence for greater complexity in these cases. It has been shown that in insulin, for example, there are intra-catenary -S-S- bonds incompatible with any simple helical chain and other evidence from the X-ray diffraction of the fibrous form of this protein shows it must have come radically different system of folding. What this is remains to be found through the combined efforts of biochemists and X-ray crystallographers aided by the theory of interatomic forces. For the direct X-ray attack we have now the advantage of being able to insert heavy atoms into the protein molecule and thus ultimately to determine the



(*b*) Folded globular aggregation with intra-catenary links.

(*c*) Coiled globular aggregation with intra-catenary links.

(*a*) Fibrous aggregation with inter-catenary links.

FIG. 1. Formation of aggregates between chain polymers with secondary valencies. Diagrammatic only.

- Main valency chains.
, Secondary valencies.

precise positions of all the atoms though the calculations, even with the assistance of electronic machines, will take many years.

In the meanwhile, we should be able to use partial indications to obtain some ideas of the general principles of protein structure. These are bound to be more complicated than they were thought to be some years ago, in particular it will be necessary to take into account not only -S-S- bridges, but also side-chain hydroxyl bonds in making model structures.

The other major biologically active polymer, nucleic acid, though not nearly so well crystallized, seems to be made on a simpler pattern than do proteins. The structure of desoxyribose nucleic acid (DNA, thymus nucleic acid) does at least seem to be dominated by a kind of spiral staircase of flat purine-pyrimidine pairs linked by hydrogen bonds belonging to two intertwined spirals joined by phosphate groups. Nucleic acid appears biologically in such concentrated localities as sperm heads in what are essentially parallel oriented fibres forming liquid crystals. Similar agglomerations seem to be found in the centre of the rods of tobacco mosaic virus and of the spheres or tetrahedra of turnip yellow virus. In all these cases and possibly everywhere, nucleic acid is associated with proteins.

Protein, on the other hand, often appears quite independently of nucleic acid in the form of definite quasi-identical molecules. These are just visible in the electron microscope and show themselves better in the X-ray studies of their numerous crystalline forms. Compact quasi-spherical molecules, such as those of the majority of soluble proteins, are much more easily transportable in cell fluids than indefinite extended chains. Their size varies from the 20 Å diameter of the insulin molecule to the nearly 200 Å diameter of haemocyanin overlapping those of the smaller viruses. Owing to the presence of both positive and negative charges on the molecular surface and their capacity for forming external hydrogen bonds, protein molecules can agglutinate into crystals holding much water. For most proteins, other than those with very elongated molecules, this effect is lost on dilution and protein solutions are Newtonian within definite ranges of pH and salt concentration. Some proteins do, and possibly all proteins can be induced to, combine more closely to give either fibres—as in the case of acid or heat denaturation—or larger spheroidal aggregates sometimes produced by pressure denaturation. These changes have to be carried out very carefully to avoid irreversible denaturation with the formation of insoluble fibres or aggregates.

It is between fibres or spheroidal aggregates of dimensions of five to ten protein molecule diameters 20–200 Å that the characteristically colloidal, long-range forces are most easily recognized. The true physical nature of these forces is still a matter of disputes; it is not clear whether they are, for instance, primarily Van der Waal's forces or depend more on mutual stimulation of ionization. Whatever the explanation, it can have nothing specifically to do with biological material as such forces are also evident in inorganic sols and clays. The appearance of long-range forces depends essentially on the size of the particles. Below a minimum they are normally weaker than those of the thermal motion of the medium. There seems, on the other hand, to be no upper limit, but with large object, such as glass plates, the forces are difficult to measure.

The structures that arise from their existence are determined by the geometry of the interacting particles. Where there are thin flat plates like those of montmorillonite the type of arrangements is regular piling at spacings from 20 to 3000 Å giving rise to irridescent layers. Similar regular layers seem to occur in mitochondria and plastids. Where there are similar rods there is regular hexagonal packing such as is observed in tobacco mosaic virus and muscle. Where groups of such particles occur free they form, if undisturbed, needle or spindle-shaped *tactoids*, if disturbed they entangle and give rise to more or less rigid *gels*. In the case of quasi-spherical particles no regular arrangement has been reported. This is presumably because here the geometrical factors are not favourable to maintaining regular order. Here the energy of alternative modes of packing does not seem to differ by as much as that of the heat motion of the medium. The existence of the forces is made evident by the spontaneous separation of such solutions into two regions of widely different concentrations. In the more concentrated phase—the so-called *coacervate*—the particles must maintain a quasi-regular short-range order—like spherical molecules in a liquid. On the average each must be surrounded by some twelve others at approximately the same distance which may range from twice to ten times the diameter of the particle.

This observed variety of behaviour of flat, fibrous and spherical particles in solution should give some indication of the complexity that may be expected in a living cell where all types of particle usually exist together and there are as well relatively large and fixed elements such as the cell wall. It should now be clear that no simple explanation can be expected to account for the internal architecture of the cell.

At the same time the knowledge of the structures at the sub-microscopic level cannot fail to be of service in the larger task of explaining the general internal behaviour of cells. Intra-cellular movements ranging from simple swelling to the full complication of meiosis and mitosis must find their ultimate explanation in some such terms. The work of the present century is in some sense a completion of that undertaken by Henderson in his classic book, *The Fitness of the Environment*. What biophysicists have done is to push further forward the limits of the inevitable behaviour of molecular systems of a degree of complexity far greater than that of the water and carbon dioxide with which they dealt.

To unravel the full complexity of cells it will be necessary to use every observational method such as phase, absorption, polarization and electron microscopy, as well as those of biochemistry and radiochemistry. Further, to give some significance to the picture thus presented, it will be necessary to push forward the physical investigation of the structural units and the forces between them.

This is already being done in many laboratories and it is a most exciting and promising field of research not only for its intrinsic interest, but also because it is typical of the new method of multiple co-operative research in which physicist, chemist and biologist, all have their part and which has been so well exemplified in the history of the Bose Institute.

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